

Mr. Johnston:

Please check the footnote on page 12 of the corrected rough draft (on page 13 of the newly typewritten copy).

APPENDIX 10

STORM FREQUENCY AND STORM DAMAGE RELATIONSHIPS
San Gabriel Watershed

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Report revised by J. F. Johnston - January 3, 1941

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Introduction

The term "frequency" as used here, in its technical sense, refers to the number of times during any selected period that storms of a particular magnitude will be equaled or exceeded. Accordingly, in a period of 50 years, a storm equaled or exceeded twice will have a frequency of 2.0 in 50 years. The average interval between such storms will be 25 years and such a storm is termed a 25-year storm or may be referred to, perhaps, as having a frequency of once in 25 years. It should be noted that the magnitude varies inversely with the frequency of occurrence, the storms and floods of lowest frequency being of the greater magnitude, and vice versa.

As commonly used, the term "frequency" indicates a rather generalized layman evaluation of the storm's magnitude over the watershed, but such an interpretation may be very misleading. This is so because a storm, like the March, 1938 storm, may be a great storm for intensities of long duration such as would be necessary for the concentration of water at the lower reaches of the watershed, but a very moderate storm for short intensities such as are required for the concentration time for small headwater areas.

Since rain patterns over southern California watersheds are more often erratic than consistent over large areas, we may, therefore, assume that if on any such watershed, only a few rain gages are read, very different storm frequencies might be derived than if an adequate number of gages are read. The watersheds under consideration in this report are inadequately supplied with rain gages and it follows that any generalized storm frequency estimate obtained from such a watershed is likely to be

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Since rain patterns over southern California watersheds are more often erratic than consistent over large areas, we may, therefore, assume that if on any such watershed, only a few rain gages are read, very different storm frequencies might be derived than if an adequate number of gages are read. The watersheds under consideration in this report are inadequately supplied with rain gages and it follows that any generalized storm frequency estimate obtained from such a watershed is likely to be

inaccurate or misleading in proportion to the erratic nature of the storm.

Frequency data should, therefore, be supplemented or modified by information, such as: (1) the extent or comprehensiveness of the data and the area to which it applies, (2) whether the emphasis is on the short time high intensities such as affect the upper reaches of a watershed, (3) whether the emphasis is on the longer sustained by moderate intensities that affect the lower reaches of the watershed, or (4) whether it is a combination of several or all of these factors and how they are combined or weighted.

Storm frequencies are usually developed for two general purposes; namely, (1) for determining how often a particular storm magnitude will be equalled or exceeded, and (2) for determining the probable magnitude of storms yet to come. These general determinations in turn may be desired for one or more of the following purposes: (1) For the purpose of determining the greatest possible peak flow that can occur within a specified period of years for some specific point or stretch along a water course - this is for the design of channels and weirs; (2) For the purpose of determining the greatest amount of water that may flow for an interval during which the flow is above a certain predetermined minimum - this is for the design of flood control reservoirs and for water storage; (3) For the determination of damages to be expected from storms likely to occur in the future.

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The factors involved in the study of flood damages (item 3) include not only the items required under 1 and 2, but many others, such as quantity of flow at which damage begins in a certain natural channel; the magnitude and distribution of successive peak flows; the present and changing condition of land use and cover; the development of the works of man along the flood courses of the waterways, etc. The effect of change of cover and other constantly changing physical aspects of a watershed on the magnitude of flood flows and consequently on flood damage is probably the most difficult factor to take into account.

It is entirely possible that by a study of stream hydrographs and corresponding damages for flood flows in representative watersheds, in both small and large areas, that a close relationship could be obtained between storm frequency and damage. This would be the most satisfactory way to approach the problem of estimating future flood damages, but the records necessary for such an undertaking would be extensive, and a thorough knowledge of both upstream and downstream watershed conditions would be necessary. For the watersheds considered in this report, the requisite storm and damage data are not available, except in rare instances, and this method of determining future flood damages is not generally applicable.

Future damage estimates must be based on 1938 storm damages

The only general storm in the San Gabriel River watershed for which any reasonably adequate damage data are available is the storm of February 27 to March 2, 1938, referred to in this report as the

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"1938 storm." There was one storm in December, 1938 which did appreciable damage but it was so scattered and of such relatively small over-all magnitude that very little organized data were obtained. Erosion damage from this December storm in some places was very great (see plate 15, photographs DG-1 and DG-2), but the areas were very local and scattered because of the large variation of intensity of the storm over the watershed.

The storm of September, 1939, according to the 24-hour precipitation, was a storm of considerable magnitude, but runoff and damage from this storm were negligible. The lack of appreciable runoff from this storm was due to the fact that the soil moisture deficiency was at its maximum at the time. This condition coupled with the moderate intensities resulted in most of the rain going into the ground.

Owing to the fact that the usual yearly local storm damage is taken for granted, it is difficult to ascertain such damage from local observers. The unreliability of damage records from storms occurring before the 1938 storm and from storms since that storm, make it necessary to predict damage from future storms largely on the basis of the 1938 storm. Thus, in order to determine future flood damages in any particular part of the watershed, it is necessary to establish a method by which the damage produced by the 1938 storm in that particular area could be quantitatively related to the total damage to be expected in that area from all damage-producing storms which will probably occur in 50 years, because the only adequate data of storm damage

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in the past 65 years of storm record is that resulting from the 1938 storm.

It might appear that any estimate of the total damage for all storms for the next 50 years, based entirely on the one storm, would, of necessity, be somewhat questionable and this is probably the case. However, it is believed that a reasonably reliable figure has been obtained by superimposing the data for the 1938 storm upon an analysis of expected storm frequency developed from the most appropriate hydrologic data of storms of record, and with the calculated result tempered by the evaluation of the incomplete data from historic storms and field observations.

Basis for determining the frequency of the 1938 storm

The only available data upon which to base the storm frequency analysis which must serve as the foundation for a storm damage study for the San Gabriel River watershed are records of past storms with respect to: (1) the one-hour maximum rainfall intensity, (2) the maximum day and maximum 24-hour rainfall, and (3) the total storm rainfall. Total storm rainfall records of a general nature are available for a great many years, though the reliability of the earliest records is somewhat questionable. Maximum day rainfall and maximum one-hour intensity records are available for a period of about 65 years at the Los Angeles Weather Bureau station. Automatic gages have been in use at some points for the past 39 years and intensity records for various periods are available, also, at over 300 other rainfall stations in the county.

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These three types of storm records are selected as the basis from which to determine storm frequencies from the standpoint of flood damage because:

- (1) the one-hour intensity is related to the peak flow;
- (2) The maximum day and maximum 24-hour rainfall are related to the maximum sustained inundating or highwater flow;
- (3) The total storm rainfall is related to the total runoff and the tendency of long continued rains to saturate the soil, causing sloughing of stream banks, higher runoff and greater erosion.

An attempt was made to determine the relative importance of these three hydrologic factors with respect to the damage-producing characteristics of a storm at any given location. The frequency of each of these three hydrologic factors was ascertained for certain storms of record back to and including the storm of 1934. Then, for each storm and locality, the three factors were combined by giving them relative weights according to the influence of each with respect to its damage potentiality. The result was an overall damage-producing index for each storm and locality based upon judgment as to the relative importance of the three factors as producers of damage.

These studies have indicated that possibly the 24-hour precipitation is the most important of the three factors and that the short time intensities and the total rainfall factors should be used only to modify the 24-hour factor. However, because of the lack of damage data, the shifting nature and localized variation in storm pattern,

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the variation in soil moisture condition before any storm and the difficulty in determining the relative effect locally of the three factors, it was deemed impossible to establish a dependable variable relationship between the three hydrologic factors with respect to the damage potentiality of the storm they represent. It was decided that nothing more than a simple relationship of these factors should be attempted now. Therefore, the over-all or total frequency curves were developed on the basis of equal weight to each factor. The procedure followed in the development of these curves was as follows:

Development of Chart No. H-1 (One-Hour Intensities)

The Los Angeles County Flood Control District has compiled rainfall data from automatic recording stations and plotted these data into station duration-intensity curves for various storm frequencies, such as 5, 10, 25, 50 and 100 years. Due to variations in topography and elevation over the watershed, the hydrologists deemed it necessary to draw duration-intensity curves for each of the storm frequencies and at eight station locations. These data were plotted and from them were produced a set of intensity frequency isohyets. The data from these curves were organized and plotted on chart No. H-1, which shows the predicted one-hour intensity for various parts of the watershed for various frequencies.

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Since the boundaries of the five major subdivisions of the watershed were selected to facilitate economic analysis, the sub-areas did not necessarily possess substantially uniform storm characteristics. For this reason, it was necessary to divide the watershed into areas or reasonably uniform hydrological characteristics in order to develop storm frequency in sufficient detail. The watershed was divided into nine such areas and these areas are referred to on the curves of the charts where necessary.

It should be explained that the values used in Chart No. H-1 are increased over the duration-intensity curves referred to above by a factor equal to .15. This increase was found necessary in order that the one-hour curves should conform with the U.S.E.D. data which forms the basis for the 24-hour and total storm curves and which was of later origin (see following section). The expected one-year intensity was determined by projecting the curves straight through from the five-year ordinate which represented the lowest period of time given by the original data to the one-year ordinate. This is consistent with the shape of all the curves on semi-logarithmic paper.

Development of Chart No. H-2 (24-hour rainfall)

The Corps of Engineers, U. S. Army, at Los Angeles had computed the maximum day rainfall for various storm frequencies at the Los Angeles Weather Bureau station. This information was published in the report, "Hydrology in the Los Angeles County Drainage Area," and dated 1939.

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It should be explained that the values used in Chart No. H-1 are increased over the duration-intensity curves referred to above by a factor equal to 1.5. This increase was found necessary in order that the one-hour curves should conform with the U.S.E.D. data which forms the basis for the 24-hour and total storm curves and which was of later origin (see following section). The expected one-year intensity was determined by projecting the curves straight through from the five-year ordinate which represented the lowest period of time given by the original data to the one-year ordinate. This is consistent with the shape of all the curves on semi-logarithmic paper.

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The series of maximum 24-hour precipitation curves (Chart No. H-2) were developed from the maximum day precipitation curves because the available data were inadequate for direct plotting of the maximum 24-hour precipitation. The maximum day isohyetal map of the U.S.E.D. (exhibit 19, "Hydrology in the Los Angeles County Drainage Area") was used to find the maximum day rainfall to be expected once in 50 years in each of the hydrologic areas. Although this exhibit is entitled "24-hour Maximum Rainfall, Frequency of Occurrence Once in Fifty Years," it would appear to be actually, "Maximum Day Rainfall." This was ascertained from a copy of the data from which the 50-year quantity for the Los Angeles station was determined.

These maximum day rainfall data were used to plot rainfall frequency curve, by the duration curve method, for Los Angeles and vicinity. It approximates a straight line on semi-logarithmic paper. This curve is indicated by the heavy dashed line marked "L.A.W.B." on Chart No. H-2 and applying to the foothills east and west of Fullerton. To get the curves for the other hydrologic areas, resort was made to the U.S.E.D. maximum day isohyetal map entitled, "24-hour Maximum Rainfall Frequency of Occurrence Once in 50 Years." This map was assumed to give the maximum day. By integrating the isohyets falling

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within each of the hydrologic areas, the weighted average of maximum day precipitation for each of these areas was established. These quantities were used for the 50-year points for each of the curves representing the remaining seven hydrologic areas as shown on Chart No. H-2.

Assuming that the curves for all the areas are of the same family as that developed above for Fullerton and vicinity, they will be straight on semi-logarithmic paper and will pass through the 50-year points as developed above. It was assumed that for any two of the eight curves, the relative magnitudes at any frequency (as for one year) would be the same as for the 50-year frequency. To apply this principle, it was necessary to determine at least one other point on one of the curves. Since a good record of 56 years exists at Glendora, this was used and the ratio of the difference in magnitude between the one-year and the 50-year points was 0.268. This ratio was used throughout to determine the one-year points of all the other curves. The eight curves for the eight hydrologic areas are represented in dashed lines in Chart No. H-2.

Since these curves represent the maximum day, it was necessary to develop a method for deriving similar curves of maximum 24-hour precipitation because the maximum day record for a single storm, such as the 1938 storm, may vary greatly from the maximum 24-hour record which is what is required. To arrive at the necessary correction, the record of maximum 24-hour rainfall for the damaging storms of record for the Los Angeles station was plotted as a duration series.

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(See Chart No. H-4 and Table H-1 for data.) This gave the curve marked "L.A.W.B. Maximum 24-Hour" indicated by the heavy solid line on Chart No. H-2 showing L.A.W.B. This curve becomes tangent to the Maximum Day Curve at about a 4-year frequency. Actually, it is believed that the curves ought to be slightly concave upward, but this refinement has too little effect upon the result to justify its further development.

The total maximum 24-hour curve, therefore, was considered to be the solid line which angles slightly at about the 4-year frequency. (Note that two points of this series of storm records coming between the 3- and 4-year period fell much below the adopted curve. This is due to the fact that the data plotted are for frequency of damaging storms and not for frequency of all storms. It is probable that these two storms should have fallen between a frequency of 1- to 2-years, but that moisture condition of the soil and cover condition of the watershed at the time caused these two storms to bring about damage such as would ordinarily result from storms of lower frequency.) To get the other maximum 24-hour curves, the following procedure was developed.

It is noticed that on the L.A.W.B. curve at the 50-year frequency, the ratio of a maximum 24-hour rainfall to maximum day rainfall is $\frac{6.0}{4.9}$ or 1.22. By a study of the precipitation phenomena and mode of record taking, it was decided that this ratio decreased as the rainfall magnitude increased. The only comparisons for maximum 24-hour rainfall of record to that of 50-year maximum days rainfall

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for the same stations, which could be made in areas of high rainfall, were for four mountain stations; namely, Opids, Hoogeys, Clear Creek and Camp Baldy. This data showed the 24-hour maximum rainfall to be about 1.1 of the average maximum day rainfall for the four stations. However, the maximum 24-hour rainfall of record at each of these stations is probably less frequent than 50 years. Therefore, the ratio of 50-year 24-hour to maximum day rainfall would be less than that found above. It was assumed to be 1.05 for the areas of high 24-hour 50-year rainfall.

Between the extreme of Los Angeles and San Gabriel Mountains above Dam 2, intermediate values of the ratio of maximum 24-hour to maximum day at 50-year frequency were assumed as follows:

1.05 above San Gabriel Dam No. 2, San Dimas,
Big Dalton and Little Dalton Canyons.

1.10 above San Gabriel Dam No. 1, and the
San Gabriel Foothills.

1.15 San Jose and Walnut Creeks, Rodeo,
La Brea, and Carbon Canyons.

1.22 U.S.W.B., Foothills east and west of
Fullerton, Coastal Plains.

From these 50-year points for maximum 24-hour, straight lines were drawn to the 4-year frequency points on the corresponding maximum day curves (Chart No. H-2). As stated above, the two curves seem to join at about this point. Between one and four year frequency, the maximum day and the maximum 24-hour curves are assumed to coincide.

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From these 50-year points for maximum 24-hour, straight lines were drawn to the 4-year frequency points on the corresponding maximum day curves (Chart No. H-2). As stated above, the two curves seem to join at about this point. Between one and four year frequency, the maximum day and the maximum 24-hour curves are assumed to coincide.

Development of Chart No. H-3 (total storm rainfall)

Data for plotting rainfall frequency curves for the San Gabriel watershed were obtained from L.A.W.B. records for damaging storms in the 58-year period from 1879 to 1938. The frequency of these storms was found by the Duration Curve method and the data for Los Angeles were plotted as a rainfall-frequency curve drawn in heavy line and marked L.A.W.B. in Chart No. H-3 (page). This curve is plotted as a straight line, fitting the plotted points as closely as possible. As in the maximum 24-hour curve, the lower plotted points (not shown) deviate from the expected direction of the curve and probably for the same reason.

The curves for other hydrologic areas were plotted relatively to the Los Angeles curve, in the ratio of their mean seasonal rainfalls. Seasonal rainfall was determined from U.S.E.D. map of Exhibit 6, "Hydrology in the Rio Hondo and San Gabriel River Basins" (1938) entitled "Isohyetals for 64-year Normal Seasonal Precipitation." The values used in each area are shown in Table H-2. A similar but more recent map is shown in Fig. ().*

Determination of 1938 storm frequency

The maximum one-hour, 24-hour and total storm factors for the 1938 storm for each of the nine hydrological areas were obtained from the U.S.E.D. isohyetals for the watershed of the one-hour, 24-hour and total storm quantities for that storm by integrating the appro-

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* See footnote 1, page 12

Table No. H-12

San Gabriel Rainfall-Frequency Data
According to Areas Covering Similar Hydrological Conditions

Hydrological and Flood Source Areas	Fr-30												Average
	One-hour storm			Maximum 24-hour storm				Total storm precipitation				:local	
	50-yr.: 1938	Frequency	50-yr. storm	1938	Max.	Max.	storm	max.	seasonal	storm	storm	1938	storm
	: in	: in	: in	: day	: 24-hr.	: in	: 24-hr.	: in	: in	: in	: in	: storm	: frequency
	: inches	: inches	: years	: inches	: inches	: inches	: in yrs.	: inches	: inches	: inches	: inches	: in yrs.	: in years
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	
1. Coastal Plains	1.40	0.5	1	4.0	4.9	4.0	18	12.0	7.25	8.0	100	40	
2. Foothills, east & west of Fullerton	1.68	0.5	1	4.9	6.0	4.5	14	13.5	8.15	9.5	150	55	
3. Carbon Canyon	1.72	0.5	1	6.0	6.9	4.5	8	15.0	9.05	9.0	39	16	
4. La Brea, Rodeo Can.	1.75	0.6	1	7.0	8.1	5.0	7	17.0	10.25	10.5	54	21	
5. San Jose, Walnut Creeks	1.80	0.6 0.5	1	7.0	8.1	5.0	7	17.0	10.25	10.0 10.5	46	18	
6. San Gabriel Mt. Foothills	1.96	0.7	1	8.5	9.4	7.0	13	22.0	13.3	14.0	70	28	
7. San Dimas, Little & Big Dalton	2.44	1.1	1	11.0	11.5	9.0	15	27.0	16.3	18.0	98	38	
8. Above San Gabriel No. 2	2.63	1.49	3	11.6	12.2	12.08	49	37.8	22.8	23.0	54	35	
9. Above San Gabriel No. 1	2.42	1.42	3	9.4	10.3	10.95	70	32.9	19.8	21.0	75	49	
L. A. Weather Bur.	1.5	0.9	3	4.9	6.0	6.18	60	15.22	9.2	11.06	150	71	

Average frequency of the 1938 storm for the upper watershed of the San Gabriel valley

32.68

priate isohyets falling within each of the hydrologic areas. These quantities were used to enter the appropriate curves of Charts H-1, H-2 and H-3 and the corresponding frequencies obtained. These values are tabulated in Table H-1, columns 3, 7 and 11. It is interesting to note the wide variation in frequency of the different storm factors for the 1938 storm for different locations in the watershed.

It having been decided to give each of the three frequencies thus obtained for any one area equal weight in arriving at a combined frequency which would be a total index of the damage-producing frequency of the 1938 storm in that locality, the three frequencies were averaged arithmetically for each area and this figure is given in Table H-2 under "Average local storm frequency." The weighted average for the 1938 storm for the watershed as a whole, developed on an area-frequency basis, was once in about every thirty-three years.

The average frequency is much higher (i.e., the magnitude was lower) than is indicated by the popular conception of the frequency of the 1938 flood and although it was a great storm for large areas, it was not generally severe for the small watersheds. Due to widespread newspaper publicity and great loss of life in the lower reaches of the larger streams, it has been popularly considered as a general storm of such magnitude as occurs only once in fifty or more years. This, as has already been pointed out, is true in the

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lower reaches of the Los Angeles, Tujunga and San Gabriel Rivers where the time of concentration is quite long, but on the smaller watersheds, the peak flow was low. The storm, however, was quite general throughout the watershed.

The intensity of precipitation, as measured by the three hydrologic factors in combination, is an index to the magnitude or damage power of the storm they represent. The magnitude of these three factors is represented by their respective frequencies and their combination (and hence, of the storm) by the combined or overall frequency of the storm. It is proposed to develop a quantitative relationship between storm magnitude (represented by storm frequency) and storm damage. Therefore, it is necessary to construct a curve showing composite storm magnitude in its relation to storm frequency.

To accomplish this, Charts H-1, H-2 and H-3 were redrawn to show precipitation magnitude in terms of the 50-year magnitude as 100%. In plotting these curves on semi-logarithmic paper, with frequency for the abscissae, and per cent of precipitation for the ordinates for each of the three hydrologic factors, all of the curves came out approximately straight. A composite of these curves will give a single curve with the ordinate at any frequency expressed as a per cent of the composite magnitude of the three factors taken at a 50-year frequency. Such a composite curve for the three factors is given in curve (A) of Chart H-5. Note here that the quantity of precipitation for the three hydrologic factors for a 20-year storm is 50% of that of a 50-year storm.

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Correlation between storm magnitude and storm damage

It is necessary now to develop correlation between storm damage and storm magnitude, as defined above. To determine a rational and accurate relationship for this correlation, it should be necessary to make a comprehensive damage survey after every damaging storm in a 50-year period and correlate the damage with the known frequency of the particular storm. Records of past storms here are inadequate, so an appraisal of historic storms is the only possible substitute. The most comprehensive material discovered was a tabulation and classification of past flood years that has been developed by the Corps of Engineers, U. S. Army. It is a chart that shows the magnitude of the floods of past years as far back as 1810 classified into three groups of storms by judgment based on historical records such as newspaper accounts, private records, etc. (see Chart H-4, on page). The three classifications are as follows:

Class 1 - high rainfall intensity for 10 to 60 minutes. Damage confined to small areas.

Class 2 - high rainfall intensity for 1 to 2 hours, following 3- or 4-day storms. Damage along river channels and loss of life.

Class 3 - rain for 2 to 4 weeks followed by rain of high intensity for 2 to 4 hours. Loss of life and great damage to property.

The U. S. Weather Bureau has been able to furnish the data on the amount of rain which fell during the maximum 24-hour period and

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Class 1 - high rainfall intensity for 10 to 60 minutes. Damage confined to small areas.

Class 2 - high rainfall intensity for 1 to 3 hours, following 3- or 4-day storms. Damage along river channels and loss of life.

Class 3 - rain for 3 to 4 weeks followed by rain of high intensity for 2 to 4 hours. Loss of life and great damage to property.

The U. S. Weather Bureau has been able to furnish the data on the amount of rain which fell during the maximum 24-hour period and

for each entire storm at the Los Angeles station for as far back as the 1879-80 season. The Corps of Engineers' classification of storms, together with the Weather Bureau rainfall data, is shown on Table No. H-1

Curve E in Chart H-5 is a composite of two estimates of flood damages from historical storms, reduced to a 50-year period, taken from the "Los Angeles and San Gabriel Rivers and their tributaries - Flood Control Report of April 23, 1938, U.S.E.D.;" and "Los Angeles and San Gabriel Rivers and their tributaries, and Ballona Creek, Flood Control Report of March 15, 1939, U.S.E.D." The first mentioned of these two records seemed to be the most comprehensive attempt to appraise past storm damage. However, in the schedule of storms, the damage for ten class-1 storms in 100 years, as listed in Chart H-4 and Table H-2, had not been appraised. From the fact of the great variation in the damage data developed, the fact that the recorded damages were almost entirely in the downstream areas only as well as the acknowledged conjectural character of the material, an attempt to apply these data directly to the headwater areas of the San Gabriel watershed would seem inappropriate. It is felt that for the type of watersheds surveyed by the U.S.D.A., the most practicable correlation of storm damage with magnitude can be accomplished by determining bottom and top limits and then developing a curve between these limits that seems to satisfy the greatest number of observed facts. To this

for each entire storm at the Los Angeles station for as far back as the 1879-80 season. The Corps of Engineers' classification of storms, together with the Weather Bureau rainfall data, is shown on Table No. H-1.

Curve B in Chart H-5 is a composite of two estimates of flood damages from historical storms, reduced to a 50-year period, taken from the "Los Angeles and San Gabriel Rivers and their tributaries - Flood Control Report of April 23, 1933, U.S.E.D.;" and "Los Angeles and San Gabriel Rivers and their tributaries, and Ballona Creek, Flood Control Report of March 15, 1933, U.S.E.D." The first mentioned of these two records seemed to be the most comprehensive attempt to appraise past storm damage. However, in the schedule of storms, the damage for ten class-I storms in 100 years, as listed in Chart H-4 and Table H-3, had not been appraised. From the fact of the great variation in the damage data developed, the fact that the recorded damages were almost entirely in the downstream areas only as well as the acknowledged conjectural character of the material, an attempt to apply these data directly to the headwater areas of the San Gabriel watershed would seem inappropriate. It is felt that for the type of watershed surveyed by the U.S.D.A., the most practicable correlation of storm damage with magnitude can be accomplished by determining bottom and top limits and then developing a curve between these limits that seems to satisfy the greatest number of observed facts. To this

Table No. H-3
Historical and Recorded Floods of the
Los Angeles Watershed, Grouped in Three
Orders of Magnitudes, 1810-1938.

1/

Flood year	Class of Flood			Rainfall at Los Angeles		Months and days of rainfall
	Magnitude			Maximum	Total storm	
	No. 1 :Small	No. 2 :Medium	No. 3 :Large	24-hour : in inches	rainfall : in inches	
1	2	3	4	5	6	7
1810-11	1			2/	2/	
1814-15	1					
1821-22		2				
1825-26			3			
1833-34		2				
1839-40			3			
1841-42		2				
1849-50		2				
1852-53		2				
1859-60	1					
1861-62			3			
1867-68		2				
1873-74	1					
1875-76	1					
1879-80	1			4.34	4.71	12/19 - 23
1883-84			3	3.63 2/	7.12	2/14 - 18
1885-86		2		3.77	6.51	1/16 - 21
1889-90			3	4.30	6.26	12/18 - 26
1892-93	1			3.75	5.96	11/26 - 12/3
1900-01	1			3.70	6.53	11/16 - 22
1902-03	1			3.35	3.37	3/24 - 25
1904-05	1			2.41	4.43	3/11 - 16
1908-09	1			3.17	5.93	1/20 - 27
1910-11	1			2.97	4.89	1/24 - 31
1913-14		2		4.26	7.04	2/18 - 21
1915-16		2		4.20	6.90	1/14 - 19
1921-22	1			2.37	7.90	12/17 - 23
1925-26	1			3.14	7.34	4/3 - 8
1926-27	1			3.35	6.40	2/10 - 16
1933-34		2		7.36	8.27	12/29 - 1/2
1937-38			3	6.28	11.06	2/27 - 3/4
Total						
129 years	15	10	6			
Frequency						
in years	4.2	8.1	21.5			

Total number of storms occurred: 31

1/ Historical data on flood magnitude in part from U. S. Engineer Office supplemented by information taken from report by H. B. Lynch on "Rainfall and Stream Run-off in Southern California since 1769."

2/ Data not available from 1810 to 1879

3/ Maximum day's rainfall. Data from report of M. F. Burke on "Flood of March 2, 1938", for the Los Angeles County Flood Control District, table VI.

end, the curve B-C of Chart H-5 was developed on the following assumptions:

- (1) The upper limits of storm magnitude will be a 50-year storm;
- (2) The lower limit will be a two-year storm;
- (3) Between these limits, the storm damage curve will be of the same shape as the storm magnitude curves.

The reasons for these assumptions are as follows:

- (1) Fifty years is the period adopted for benefit-cost analyses.

The probability exists that in this period of time, one storm frequency may be equal to or greater than 50 years, two equal to or greater than 25 years, three equal to or greater than 33 years, etc. But, the greater storm may be of any frequency, even 1000 years more or less, and the others may be greater than the minimum as expressed by the frequency. Nevertheless, the accuracy with which all the factors involved may be worked out does not justify improvement beyond assuming an ideal alignment of values according to established procedure.

- (2) The lower limit is the smallest magnitude of storm from which appreciable damage can be expected. Field observations and damage surveys show that much damage is done every year in localized areas where intensities appear to be greater than the average yearly intensity. (See photographs on erosion and deposition). Also, because channels in the cones and upper watershed areas are usually poorly defined, the lower limit of storm magnitude that will cause damage is much lower than should

and, the curve B-C of Chart E-5 was developed on the following assumption:

assumptions:

- (1) The upper limits of storm magnitude will be a 50-year storm;
- (2) The lower limit will be a two-year storm;
- (3) Between these limits, the storm damage curve will be of the same shape as the storm magnitude curves.

The reasons for these assumptions are as follows:

(1) Fifty years is the period adopted for benefit-cost analyses. The probability exists that in this period of time, one storm frequency may be equal to or greater than 50 years, two equal to or greater than 25 years, three equal to or greater than 17 years, etc. But, the greater storm may be of any frequency, even 1000 years more or less, and the others may be greater than the minimum as expressed by the frequency. Nevertheless, the accuracy with which all the factors involved may be worked out does not justify improvement beyond assuming an ideal alignment of values according to established procedure.

(2) The lower limit is the smallest magnitude of storm from which appreciable damage can be expected. Field observations and damage surveys show that much damage is done every year in localized areas where intensities appear to be greater than the average yearly intensity. (See photographs on erosion and deposition). Also, because channels in the cones and upper watershed areas are usually poorly defined, the lower limit of storm magnitude that will cause damage is much lower than should

be expected in the lower reaches of the watershed. After careful study, a two-year storm was adopted as representing no damage.

(3) The damage curve is assumed to closely follow the storm magnitude curve for three important reasons:

(a) because it seems reasonable that after the existing drainage system is taxed to its no-damage capacity, any additional precipitation will begin to produce damage and that on the average, such damage will be approximately in proportion to the excess magnitude of precipitation over the no-damage level. In some locations, the increase will be greater and in some, it will be less. Good judgment is the only possible way to determine the proper ratio to use;

(b) general storm damage begins at a two-year storm when the composite quantitative expression of the storm in terms of the three hydrologic factors is 50% of the 50-year storm; that is, it begins at a high rate of storm magnitude;

(c) the damage for the projected 50-year period is to be largely estimated from the 1938 storm, and the March, 1938 storm had a frequency of only 33 years. Therefore, any discrepancy in the ratio of damage to magnitude below the 33-year point on the curve will tend to be compensated by a discrepancy in the opposite direction above the 33-year point.

Chart No. H-5 gives the ratio of damages to be expected from a storm of any known frequency, expressed as a percentage of the damages resulting from a 50-year storm as an unknown quantity but established as at 100%. The answer desired is an expression of the total damages expected from all storms during a 50-year period in terms of the damage from known storms. In this case, it is only one storm, the 1938 storm.

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(b) General storm damage begins at a two-year storm when the composite quantitative expression of the storm in terms of the three hydrologic factors is 50% of the 50-year storm; that is, it begins at a high rate of storm magnitude;

(c) the damage for the projected 50-year period is to be largely estimated from the 1938 storm, and the March, 1938 storm had a frequency of only 33 years. Therefore, any discrepancy in the ratio of damage to magnitude below the 33-year point on the curve will tend to be compensated by a discrepancy in the opposite direction above the 33-year point.

Chart No. B-5 gives the ratio of damages to be expected from

a storm of any known frequency, expressed as a percentage of the damages resulting from a 50-year storm as an unknown quantity but established as at 100%. The answer desired is an expression of the total damages expected from all storms during a 50-year period in terms of the damage from known storms. In this case, it is only one storm, the

1938 storm.

Damage From All Storms in 50 Years in Terms of Damage from 1938 Storm

At the time of development of the Los Angeles report, it was felt that for the smaller watersheds, the U.S.E.D. classification of storms did not include all damaging storms^{1/}, so one more class 1 magnitude storm was added which was to have compensated for all the storms of less magnitude than the lowest class which is recorded to have caused damage. Since this report, additional observation on the season to date has shown that storms with frequencies as low as two years do appreciable general damage, and that damage, on isolated area, from erosion, washing and siltation is appreciable every year. (See plate _____). This would bring the total damaging storms for a 50-year period to practically twenty-five, and this is the number of storms used to develop curve B-C of Chart H-5.

The plotting of the twenty-five storms as curve "B-C" of Chart No. H-5 was by the average interval between floods or the "California" method.^{2/} That is, there have been determined to be two storms during a 50-year period which equal or exceed the twenty-five year storm, and they are plotted at twenty-five and fifty-year frequencies. The same analysis can be applied to the other storms

^{1/} U.S.D.A. Field Flood Control Coordinating Committee No. 18, Survey Report for the L.A. River, Appendices, See B, page 15.

^{2/}

At the time of development of the Los Angeles report, it was felt that for the smaller watersheds, the U.S.W.D. classification of storms did not include all damaging storms, so one more class I magnitude storm was added which was to have compensated for all the storms of less magnitude than the lowest class which is recorded to have caused damage. Since this report, additional observation on the season to date has shown that storms with frequencies as low as two years do appreciable general damage, and that damage, on isolated area, from erosion, washing and siltation is appreciable every year. (See plate _____). This would bring the total damaging storms for a 50-year period to practically twenty-five, and this is the number of storms used to develop curve B-C of Chart H-5. The plotting of the twenty-five storms as curve "B-C" of Chart No. H-5 was by the average interval between floods or the "California" method. That is, there have been determined to be two storms during a 50-year period which equal or exceed the twenty-five year storm, and they are plotted at twenty-five and fifty-year frequencies. The same analysis can be applied to the other storms

plotted. For example, there must be five storms which equal or exceed the ten-year storm in a fifty-year period according to the accepted definition of storm frequency, and an average distribution of these storms on the curve will be 50, 25, 16.7, 12.5, 10-year, etc., storm frequencies.

The reason for using this method of plotting is that if the duration method is used, a storm is plotted at the mid-point of the division of the time axis that represents that storm, whereas for the purpose of constructing a damage curve, the storms must be storms that are assumed to actually occur and their magnitude must be the actual magnitudes given.

The sum of all ordinates for the twenty-five storms was computed and came out to be 696% or, in other words, all damages over a 50-year period from all storms would be 6.96 times the damage to be expected from the maximum 50-year storm. To use this curve, it is only necessary to know the frequency of one storm and the damage it incurred. With its frequency established, the value of its ordinate on the curve may be determined. By dividing this value into the 696%, there is obtained the 50-year storm damage factor. By multiplying the money value of damages from this storm by the 50-year storm-damage factor of 6.96, the estimated damages from all storms for the area for the next fifty years will be determined in money.

plotted. For example, there must be five storms which equal or exceed the ten-year storm in a fifty-year period according to the accepted definition of storm frequency, and an average distribution of these storms on the curve will be 30, 35, 40, 45, 50-year, etc., storm frequencies.

The reason for using this method of plotting is that if the duration method is used, a storm is plotted at the mid-point of the division of the time axis that represents that storm, whereas for the purpose of constructing a damage curve, the storms must be storms that are assumed to actually occur and their magnitude must be the actual magnitudes given.

The sum of all ordinates for the twenty-five storms was computed and came out to be 636% or, in other words, all damages over a 50-year period from all storms would be 6.36 times the damage to be expected from the maximum 50-year storm. To use this curve, it is only necessary to know the frequency of one storm and the damage it incurred. With its frequency established, the value of its ordinate on the curve may be determined. By dividing this value into the 636%, there is obtained the 50-year storm damage factor. By multiplying the money value of damages from this storm by the 50-year storm-damage factor of 6.36, the estimated damages from all storms for the year for the next fifty years will be determined in money.

Table No. H-3.

The Frequency of the 1938 Storm for Subareas
of the San Gabriel Watershed and the Ratio of Damage
Potentials of 50 Years of Future Storms
to that of the 1938 Storm.

Flood source	Area in:	Frequency of March 2, 1938 storm				Ratio of total
areas and sub-	sq.mi.:	Based on:	Based on:	Based on:	Based on the:	50-year damage
areas	:	total	24-hour	max. 1-hr:	3 weighted	to 1938 storm
:	:	rainfall:	rainfall:	rainfall:	factors :	damage
(1)	(2)	(3)	(4)	(5)	(6)	(7)
<u>Area No. 1</u>						
Subarea "A"	40.42	54	22	3	26	8.76
Subarea "B"	161.58	75	29	3	36	7.76
Subarea "C"	8.80	98	15	1	38	7.61
Subarea "D"-1	15.11	98	15	1	38	7.61
Subarea "D"-2	10.15	70	13	1	28	8.49
<u>Area No. 2</u>						
Subarea "A"	3.30	98	15	1	38	7.61
Subarea "B"	8.41	70	13	1	28	8.49
Subarea "C"	4.49	98	15	1	38	7.61
Subarea "D"	2.73	70	13	1	28	8.49
Subarea "E"	9.25	70	13	1	28	8.49
Subarea "F"	15.92	98	15	1	38	7.61
Subarea "G"	2.57	70	13	1	28	8.49
Subarea "H"	7.81	46	7	1	18	10.24
Subarea "I"	2.30	70	13	1	28	8.49
Subarea "J"	12.34	70	13	1	28	8.49
Subarea "K"	26.23	46	7	1	18	10.24
Subarea "L"	6.18	46	7	1	18	10.24
Subarea "M"	2.18	46	7	1	18	10.24
Subarea "N"	12.36	46	7	1	18	10.24
<u>Area No. 3</u>						
Subarea "A"	3.91	70	13	1	28	8.49
Subarea "B"	80.23	46	7	1	18	10.24
<u>Area No. 4</u>						
Subarea "A"	23.40	54	7	1	21	9.53
Subarea "B"	17.90	39	8	1	16	10.79
Subarea "C"	2.05	150	14	1	55	6.76
Subarea "D"	3.05	150	14	1	55	6.76
Subarea "E"-1	37.00	150	14	1	55	6.76
Subarea "E"-2	98.84	100	18	1	40	7.48
<u>Area No. 5</u>						
Entire area	84.70	100	18	1	40	7.48
Total area	703.21	Average for watershed:			32.68	8.05

Total Damage % = 696%

In Table No. H-3 are tabulated the three individual storm factors, the average local storm frequency (column 6), and in the last column the factors for the sub-areas considered by which the damages from the 1938 flood must be multiplied in order to obtain the total assumed 50-year damage for that area. These values have been used to obtain the total flood damage for the fifty-year period over which the flood control estimates have been calculated. Note that the first six columns are a reorganization of Table No. H-1 according to sub-areas instead of hydrologic areas. Column 7 was obtained by applying the factors in column 6 to curve "B-C" of Chart No. H-5.

It is of interest to note that the magnitude of Class 1, 2 and 3 storms as developed in the U.S.D.A. Flood Control Report for the Los Angeles River watershed fell slightly above the damage curve developed in this report, and this seems consistent with the physical and economic differences between the two watersheds.

Erosion from All Storms in 50 Years in Terms of Erosion from 1938 Storm

From the data available, it is impossible to develop any well authenticated erosion analysis so in any case, observation and judgment are the principal sources of information. Erosion from the watershed was considered, therefore, to be proportional to damage through the 7 to 50 year frequencies. The upper part of the erosion potential curve is felt to be approximately coincident with the damage curve but below the 7-year frequency erosion potential of any storm is definitely above damage potential.

In Table No. H-3 are tabulated the three individual storm factors, the average local storm frequency (column 6), and in the last column the factors for the sub-areas considered by which the damages from the 1938 flood must be multiplied in order to obtain the total assumed 50-year damage for that area. These values have been used to obtain the total flood damage for the fifty-year period over which the flood control estimates have been calculated. Note that the first six columns are a reorganization of Table No. H-1 according to sub-areas instead of hydrologic areas. Column 7 was obtained by applying the factors in column 6 to curve "B-C" of

Chart No. H-5.

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Erosion from All Storms in 50 Years in Terms of Erosion from 1938 Storm

From the data available, it is impossible to develop any well authenticated erosion analysis so in any case, observation and judgment are the principal sources of information. Erosion from the watershed was considered, therefore, to be proportional to damage through the 7 to 50 year frequencies. The upper part of the erosion potential curve is felt to be approximately coincident with the damage curve but below the 7-year frequency erosion potential of any storm is definitely above damage potential.

Observation has shown that considerable erosion occurs in the average yearly rains, and the fact that often more than one yearly storm occurs necessitates that for erosion potential purposes, the curve be made actually to include a greater number of storms than 25. Storms up to a 7-year frequency, are capable of cutting through the loose topsoil to the plough sole at which point much greater resistance to erosion is encountered. For these reasons, the "erosion potential" curve below the 7-year frequency has been drawn in by judgment as indicated by curve D in Chart No. H-6.

The per cent of erosion potential of all storms in terms of the 50-year storm is 891%. The ratio of total 50 years of potential erosion to the erosion magnitude of the 1938 storm (the erosion factors) for each of the sub-areas are given in column 7 of Table No. H-4. Other values in Table H-4 are the same as in Table H-3.

Observation has shown that considerable erosion occurs in the average yearly rains, and the fact that often more than one yearly storm occurs necessitates that for erosion potential purposes, the curve be made actually to include a greater number of storms than 35. Storms up to a 7-year frequency, are capable of cutting through the loose topsoil to the plough sole at which point much greater resistance to erosion is encountered. For these reasons, the "erosion potential" curve below the 7-year frequency has been drawn in by judgment as indicated by curve D in Chart No. H-6.

The per cent of erosion potential of all storms in terms of the 50-year storm is 89%. The ratio of total 50 years of potential erosion to the erosion magnitude of the 1938 storm (the erosion factors) for each of the sub-areas are given in column 7 of Table No. H-4. Other values in Table H-4 are the same as in Table H-3.

May 23, 1940

Table No. H-4.

The Frequency of the 1938 Storm for Subareas
of the San Gabriel Watershed and the Ratio of Erosion
Magnitude Potentials of 50-years of Future
Storms to that of the 1938 Storm

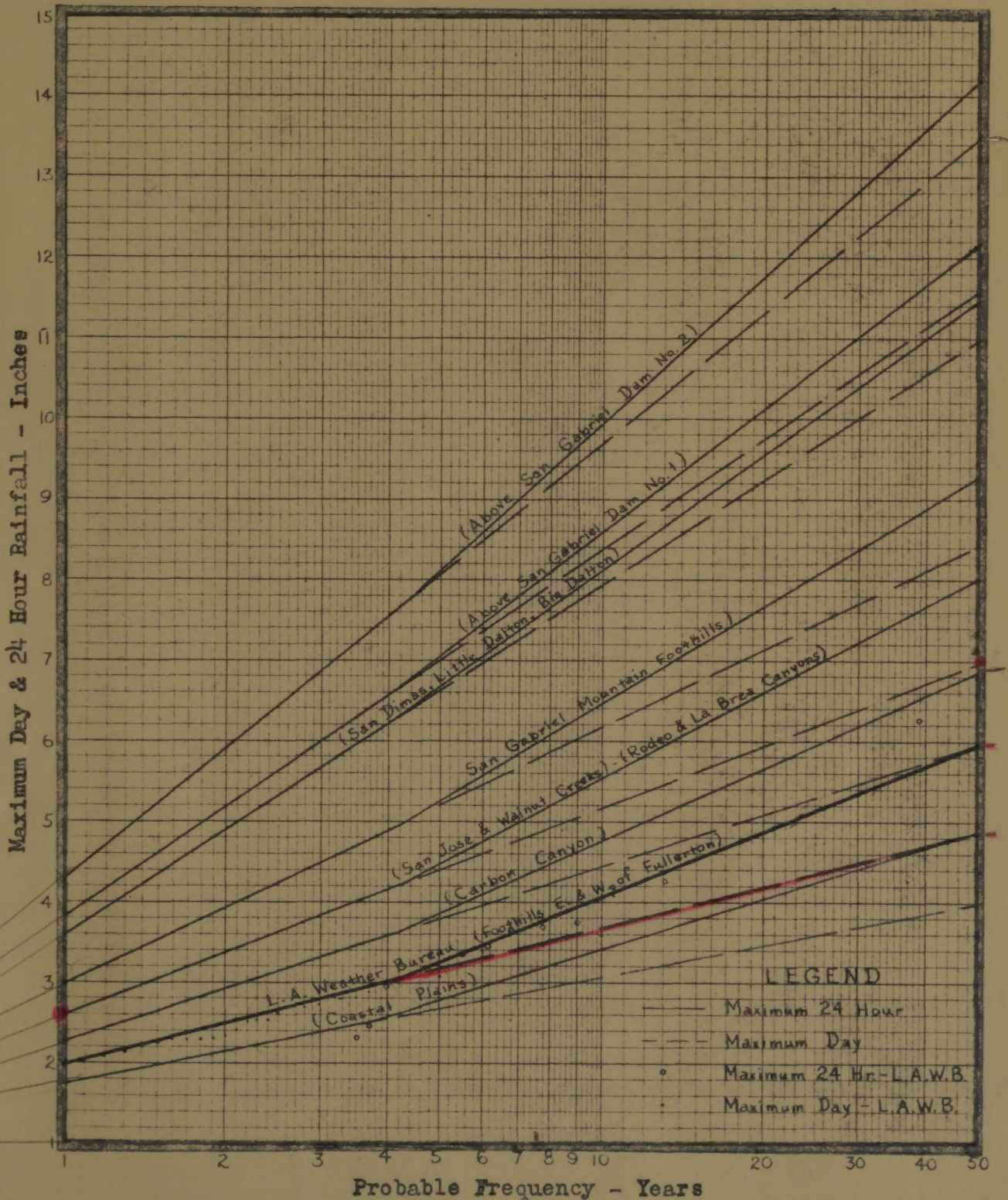
Flood Source Areas & Sub-areas	:Area in: :Sq. Mi.:	Frequency of March 2, 1938 Storm	:Ratio of total 50-yr			
	:total	:24-hour	:Erosion Magnitude to			
	:rainfall:	:rainfall:	:1938 Storm Erosion Mag-			
		:Max.1-hr:age of 3	:nitide			
		:factors				
1	2	3	4	5	6	7
<u>Mountain Area</u>						
<u>Area No. 1</u>						
Subarea "A"	40.42	54	22	3	26	11.1
Subarea "B"	161.58	75	29	3	36	9.9
Subarea "C"	8.80	98	15	1	38	9.7
Subarea "D"-1	15.11	98	15	1	38	9.7
<u>Area No. 2</u>						
Subarea "C"	4.49	98	15	1	38	9.7
Subarea "F"	15.92	98	15	1	38	9.7
Subarea "I"	2.30	70	13	1	28	10.9
<u>Valley Area</u>						
<u>Area No. 1</u>						
Subarea "D"-2	10.15	70	13	1	28	
<u>Area No. 2</u>						
Subarea "A"	3.30	98	15	1	38)	
Subarea "B"	8.41	70	13	1	28)	
Subarea "D"	2.73	70	13	1	28)	
Subarea "E"	9.25	70	13	1	28)	
Subarea "G"	2.57	70	13	1	28)	
Subarea "H"	7.81	46	7	1	18)	- 11.9
Subarea "J"	12.34	70	13	1	28)	
Subarea "K"	26.23	46	7	1	18)	
Subarea "L"	6.18	46	7	1	18)	
Subarea "M"	2.18	46	7	1	18)	
Subarea "N"	12.36	46	7	1	18)	
<u>Area No. 3</u>						
Subarea "A"	3.91	70	13	1	28)	- 13.0
Subarea "B"	80.23	46	7	1	18)	
<u>Area No. 4</u>						
Subarea "A"	23.40	54	7	1	21)	
Subarea "B"	17.90	39	8	1	16)	
Subarea "C"	2.05	150	14	1	55)	- 9.04
Subarea "D"	3.05	150	14	1	55)	
Subarea "E"-1	37.00	150	14	1	55)	
Subarea "E"-2	98.84	100	18	1	40)	
<u>Area No. 5</u>						
Entire Area	84.70	100	18	1	40	9.6
Total Area	703.21	Average for Watershed:			32.68	

CHARTS H-1 to H-6, inclusive

Chart H-2

MAXIMUM DAY & 24 HOUR INTENSITY
FREQUENCY CURVES

San Gabriel River Watershed



To accompany Survey Report
Date _____ File _____

Source of data _____

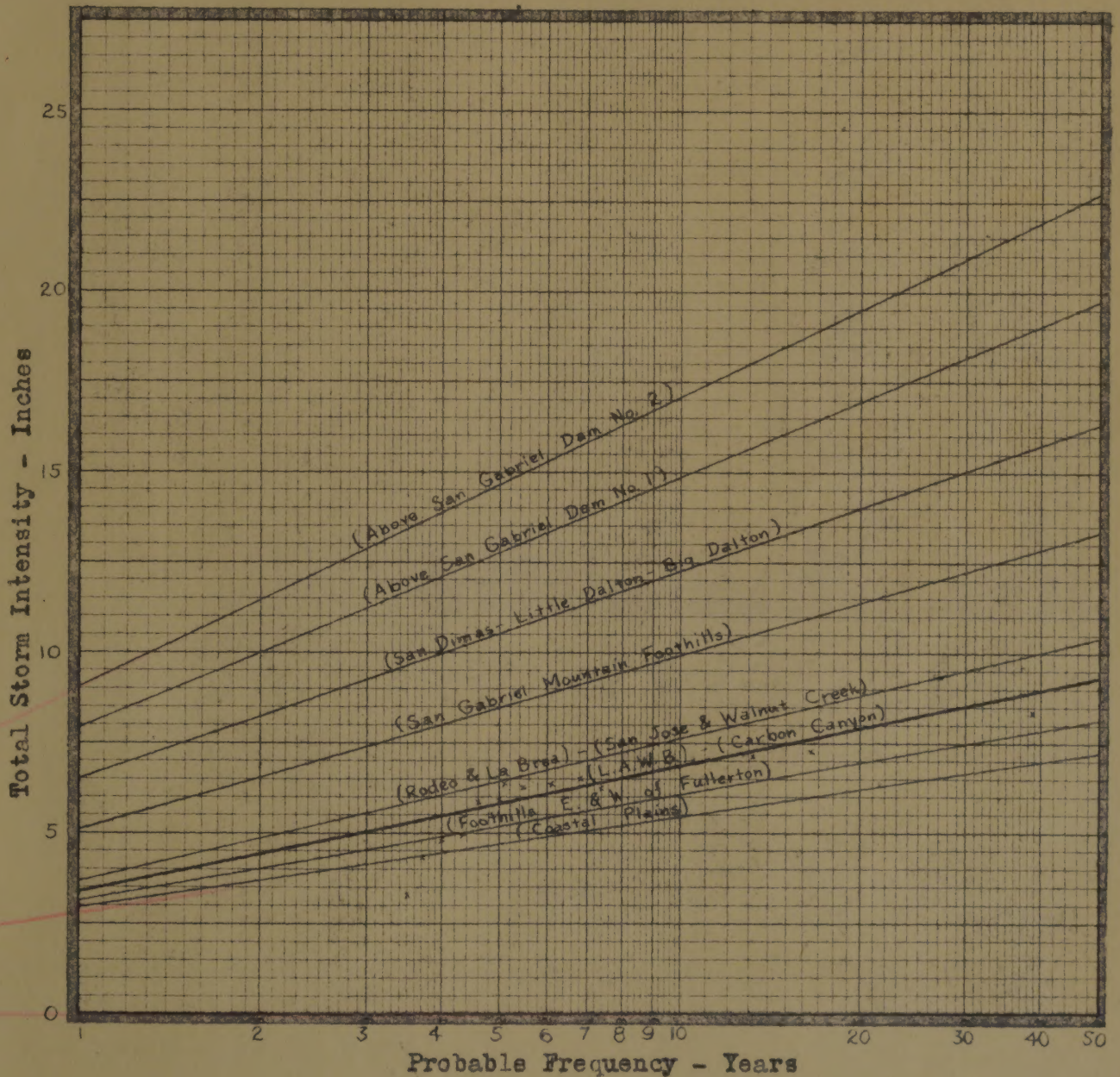
Prepared under direction of Field Coordinating Committee 18

U.S. DEPARTMENT OF AGRICULTURE
FLOOD CONTROL SURVEYS
Berkeley, Calif.

Chart H-3

TOTAL STORM RAINFALL FREQUENCY CURVES

San Gabriel River Watershed



To accompany Survey Report
Date _____ File _____

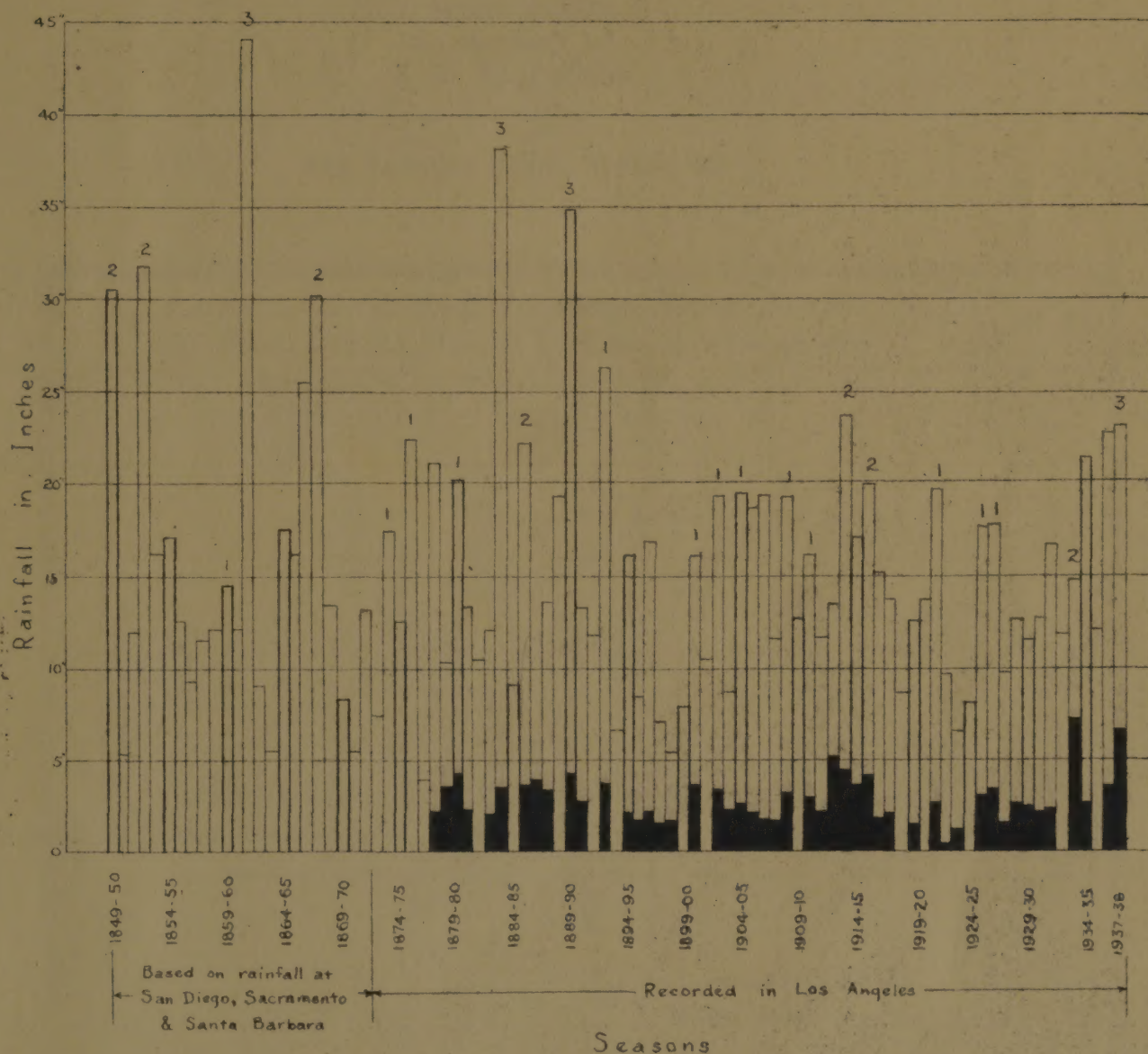
Source of data _____

Prepared under direction
of Field Coordinating
Committee 18

U. S. DEPARTMENT OF AGRICULTURE
FLOOD CONTROL SURVEYS
Berkeley, Calif.

CHART H-4

SEASONAL ANNUAL & MAXIMUM DAY RAINFALL



EXPLANATION OF FLOOD MAGNITUDES

(As indicated by the figures in parenthesis)

LEGEND

□ Total Seasonal Rainfall

■ Maximum Daily Rainfall

- (1) Indicates high rainfall intensity for 10 to 60 minutes. Damage confined to small area.
- (2) Indicates high rainfall intensity for 1 to 2 hours following 3 or 4 day storms. Damage along river channel - loss of life.
- (3) Indicates rain for 2 to 4 weeks followed by rain of high intensity for 2 to 4 hours. Loss of life and great damage to property.

To accompany Survey Report
Date

File

Prepared under direction
of Field Coordinating
Committee 18

U.S. DEPARTMENT OF AGRICULTURE
FLOOD CONTROL SURVEYS
Berkeley, Calif.

Chart H-5

CURVES OF STORM MAGNITUDE and STORM DAMAGE In Percent of A 50 YEAR STORM

SAN GABRIEL RIVER WATERSHED

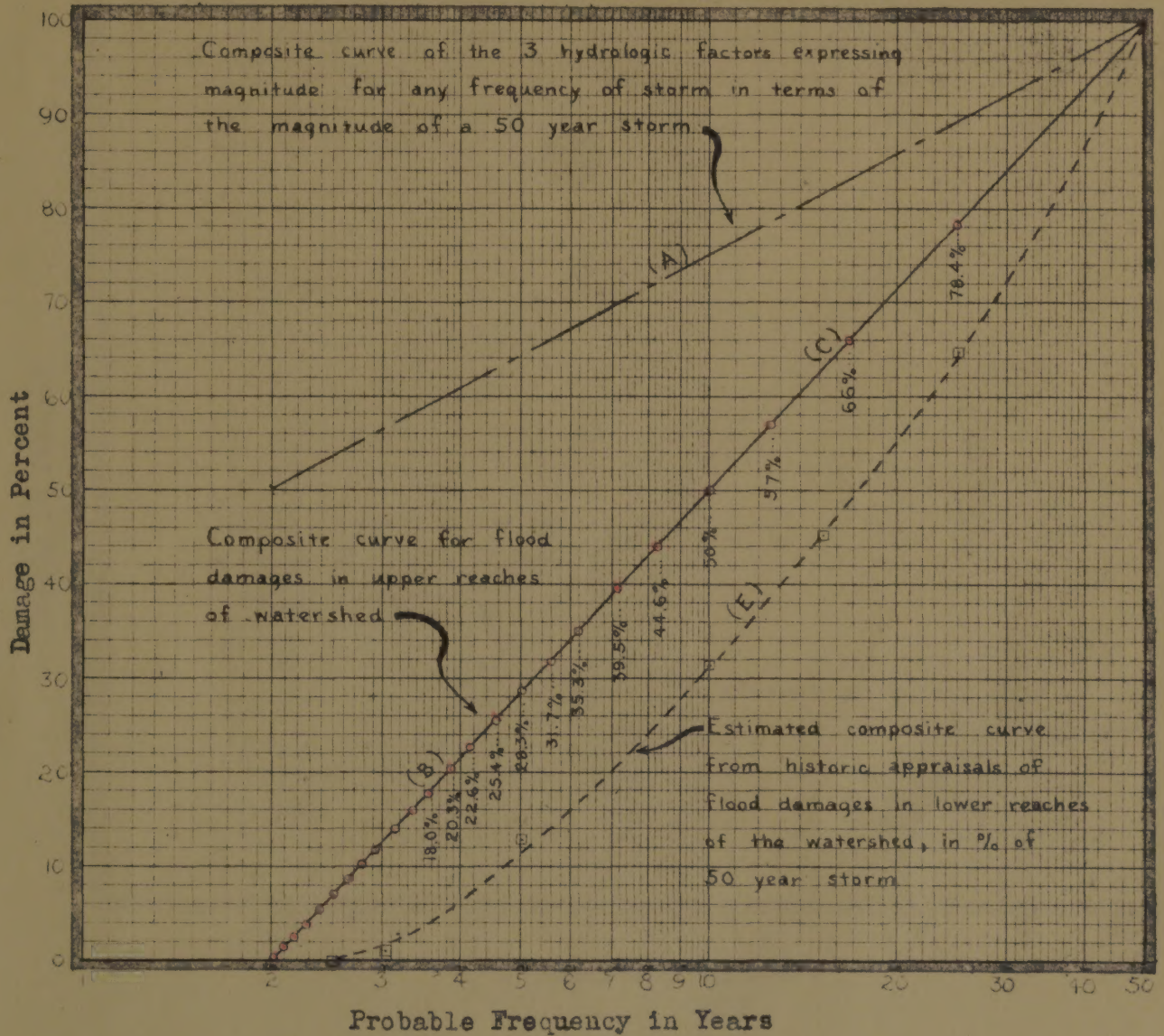
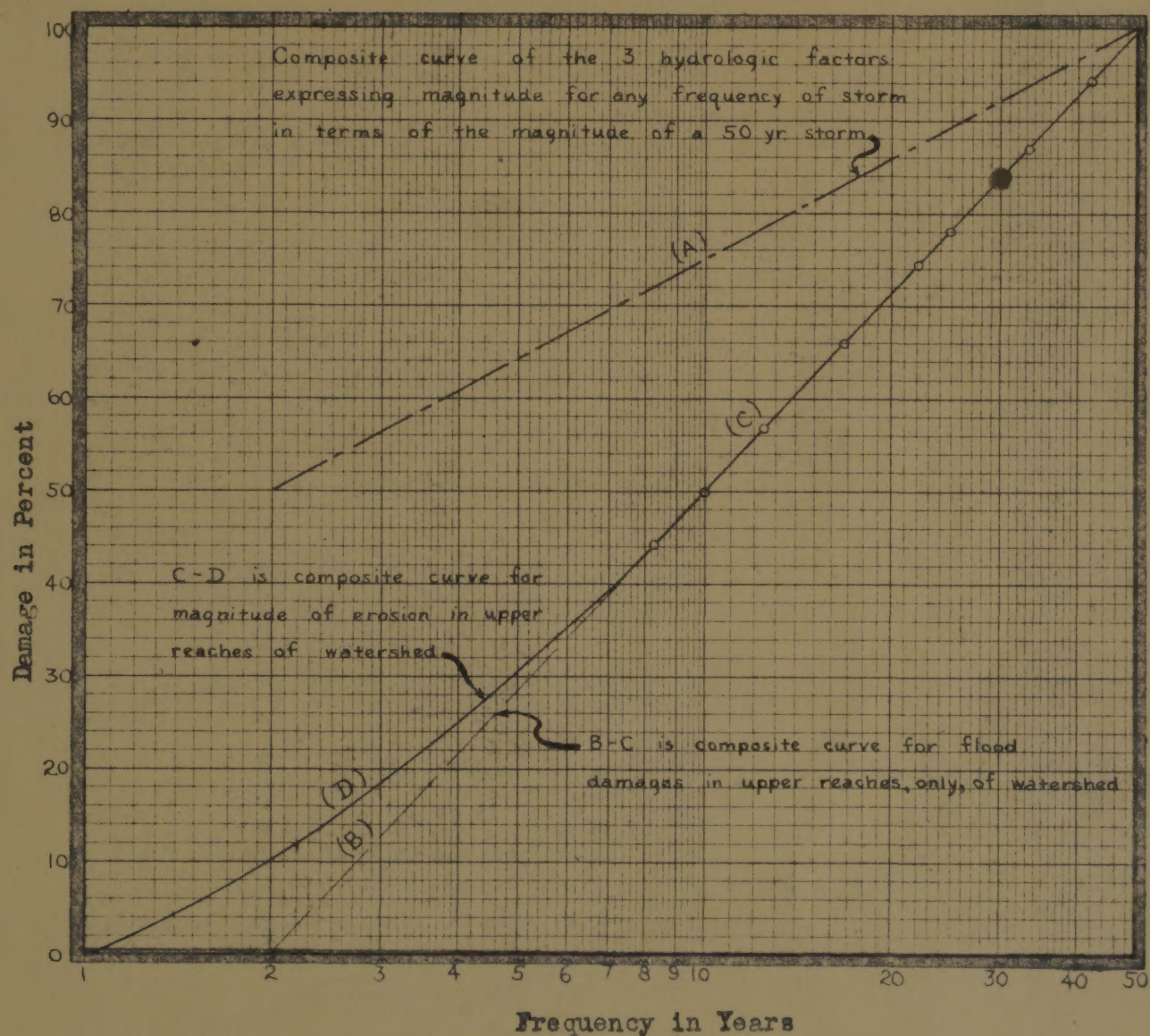


Chart H-6

CURVE for DEVELOPING EROSION POTENTIAL for 50 YEAR PERIOD

San Gabriel River Watershed



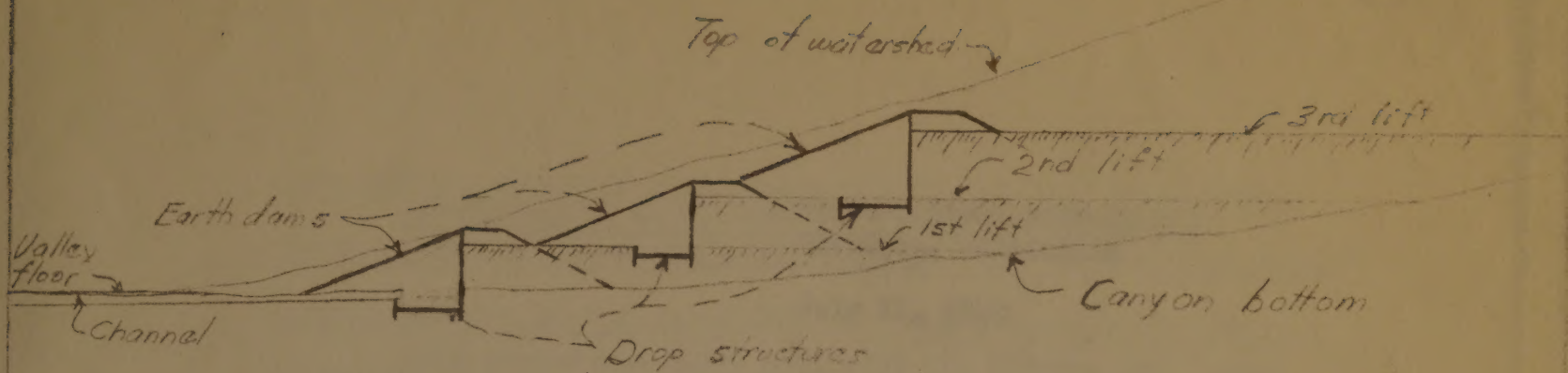
To accompany Survey Report

Date File

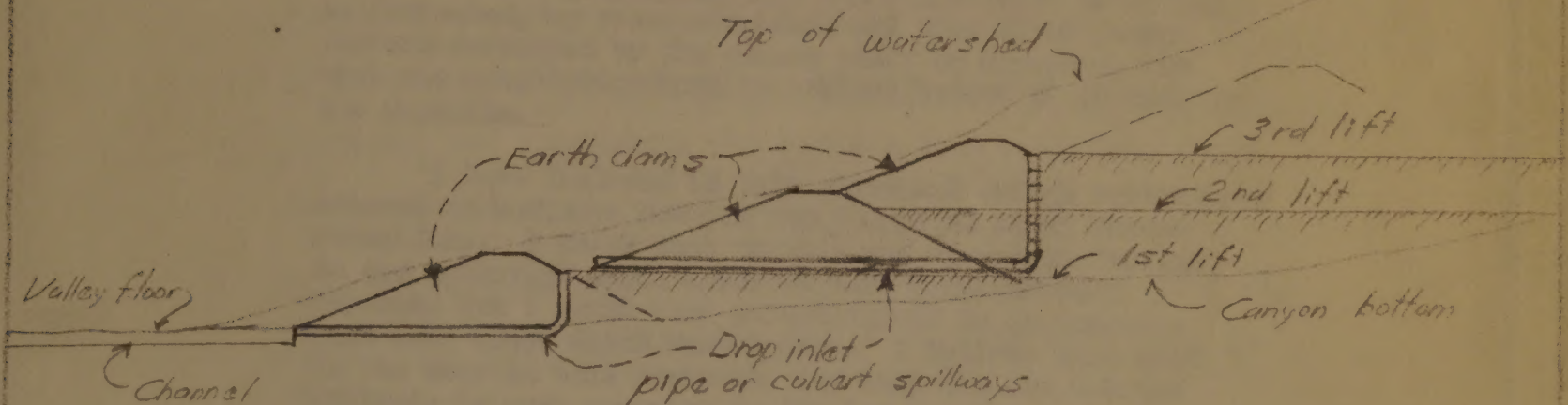
Source of data

Prepared under direction of Field Coordinating Committee 18

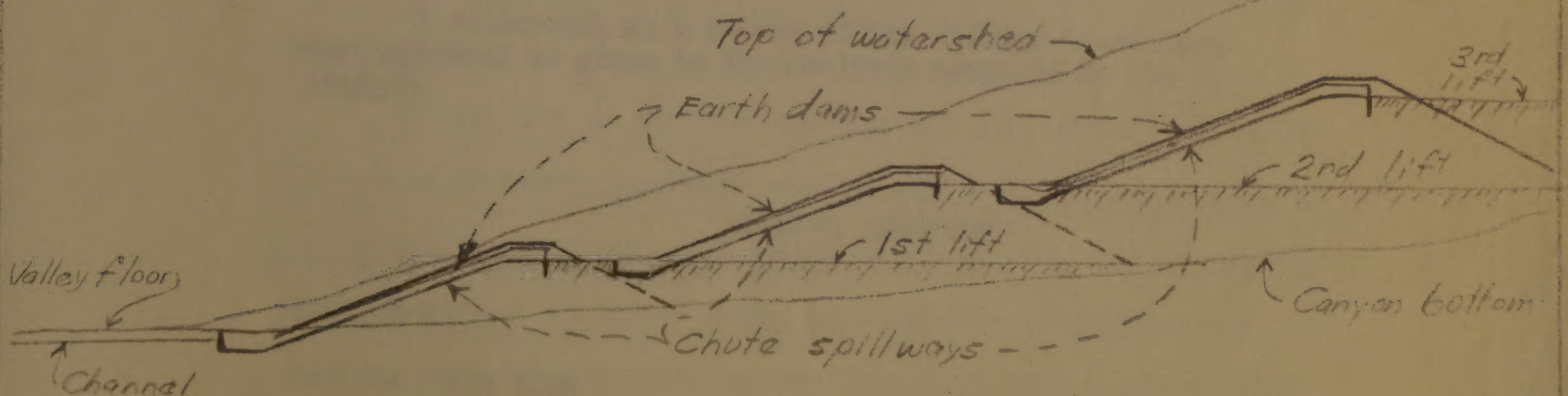
U. S. Department of Agriculture
Flood Control Surveys
Berkeley, Calif.



EARTH DEBRIS DAMS WITH DROP STRUCTURE SPILLWAYS



EARTH DEBRIS DAMS WITH DROP INLET SPILLWAYS



EARTH DEBRIS DAMS WITH CHUTE SPILLWAYS

ALTERNATE TYPES OF PROGRESSIVE LIFT DEBRIS DAM
CONSTRUCTION AND SPILLWAYS

Def. 2-11-41 F.C.-R01

Flood Control Surveys
Glendora, California

July 17, 1940

MEMORANDUM TO MR. KRAEBEL

I enclose a statement incorporating my recommendations concerning hydrology for the San Gabriel watershed. As indicated, my recommendations are that storm damage factors developed by the survey staff be approved, but that the descriptive text be revised before it is used in the appendix.

I have included in this statement enough explanatory comment to indicate how and why I arrived at my recommendations. I think that we must not expect perfection in our hydrology until after we have prepared many reports, but I think each effort should be an improvement over those which went before. I believe that such is the case in this instance, and that the San Gabriel analysis is much superior to the Los Angeles analysis.

Inasmuch as we have not received any authoritative instructions from the Washington office, we are compelled to use our own judgment, in order to give to the Project Leader some definite basis for proceeding.

I recommend, as a member of the Working Committee, that approval be given to the analysis prepared by the project.

JOHN P. JOHNSTON

Enclosure

cc's to - Mr. Ilch
 Mr. King
 Mr. Barrett
 Mr. Amidon

Food Control Bureau
Washington, California

July 17, 1945

MEMORANDUM TO MR. KENNEDY

I enclose a statement regarding my recommendations concerning hydrology for the San Gabriel watershed. As indicated, my recommendations are based on data developed by the survey staff as approved. It is noted that the hydrologic data be revised before it is used in the Appendix.

I have included in this statement enough explanatory comments to indicate how and why I arrived at my recommendations. I think that we must not expect perfection in our hydrology until after we have prepared many reports, but I think each effort should be an improvement over those which went before. I believe that such is the case in this instance, and that the San Gabriel analysis is much superior to the Los Angeles analysis.

Inasmuch as we have not received any authoritative instructions from the Washington office, we are compelled to use our own judgment, in order to give to the Project leader some definite basis for proceeding.

I recommend, as a member of the Working Committee, that approval be given to the analysis prepared by the Project.

JOHN F. KENNEDY

Enclosure

cc's to - Mr. Tish
Mr. King
Mr. Barrett
Mr. Anderson

MEMORANDUM BY J. P. JOHNSTON CONCERNING HYDROLOGY
FOR SAN GABRIEL

This memorandum deals only with the theory, and I have not checked the calculations. For two and one-half days, I have carefully studied this matter. I am fully aware of the complexities and of the many controversial points. I do not pose as a competent authority. However, we must arrive at a decision, and I am making the decision that seems best to me in the present state of my knowledge.

I RECOMMEND THAT THE STORM DAMAGE FACTORS DEVELOPED BY THE SURVEY STAFF BE APPROVED. THE DESCRIPTIVE TEXT NEEDS REVISION.

COMMENT.

There is one fundamental new concept introduced in the San Gabriel which makes the analysis different from that for the Los Angeles.

In the case of the Los Angeles, the key assumption relating damage to storm magnitude was that equal damage was caused by all storms of group one, all storms of group two, and all storms of group three. In other words, an arbitrary evaluation was placed upon arbitrary grouping of historical storms established by the U.S.E.D.

In the case of the San Gabriel, an entirely different approach is made. Damage is assumed to be proportional to storm

MEMORANDUM BY J. F. JOHNSON CONCERNING HIGHWAY
FOR NEW BRIDGE

This memorandum deals only with the theory, and I have

not checked the calculations. For two and one-half days, I have carefully studied this matter. I am fully aware of the complexity and of the many controversial points. I do not pose as a competent authority. However, we must arrive at a decision, and I am making the decision that seems best to me in the present state of my knowledge.

I recommend that the storm damage factors mentioned in the survey be removed. The tentative report which will be

COMMENT

There is one fundamental new concept introduced in the San Gabriel which makes the analysis different from that for the Los Angeles.

In the case of the Los Angeles, the key assumption relating damage to storm magnitude was based upon the fact that all storms of group one, all storms of group two, and all storms of group three. In other words, an arbitrary evaluation was placed upon arbitrary grouping of historical storms established by the U.S.N.S.

In the case of the San Gabriel, an entirely different approach is made. Damage is assumed to be proportional to storm

magnitude in excess of a no damage level. The damage resulting from a fifty-year storm is taken as 100%. For any storm of intermediate magnitude, the damage will be proportional to the excess of magnitude over that of a two-year storm.

This concept assumes that infiltration, channel storage, surface detention, existing channel and other facilities, etc. are sufficient to fully account for the potential damaging effect of any storm smaller than that represented by a two-year frequency, and that damage begins at zero with such a storm.

For any storm, there will be a no damage component equal in value to that assumed for the two-year storm. The damage produced by any storm compared with that produced by a fifty-year storm, is proportional to the relative excesses of magnitude over the constant no damage component represented by the magnitude of the two-year storm.

The money damage value of the fifty-year or 100% storm (and therefore of any other storm) is established by applying the 1938 storm damage value as the ordinate at the point on the frequency axis representing the frequency of the 1938 storm according to its three hydrologic factors.

The use of the three hydrologic factors in the determination of frequency is not a new concept because it was used in the Los Angeles Report, and has not been challenged. It seems logical to us, when considering the watershed area, rather than merely

magnitude in excess of a no damage level. The damage resulting from a fifty-year storm is taken as 100%. For any storm of intermediate magnitude, the damage will be proportional to the excess of magnitude over that of a two-year storm.

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For any storm, there will be a no damage component equal in value to that assumed for the two-year storm. The damage produced by any storm compared with that produced by a fifty-year storm, is proportional to the relative excesses of magnitude over the constant no damage component represented by the magnitude of the two-year storm.

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The use of the three hydrologic factors in the determination of frequency is not a new concept because it was used in the Los Angeles Report, and has not been challenged. It seems logical to us, when considering the watershed area, rather than merely

peak flood flow, which might better be the basis for frequency for considering downstream construction.

By virtue of the fact that both the hydrologic elements and the damage figures for the 1938 storm are localized for the San Gabriel, the analysis is pointed directly at the San Gabriel, and is not a translation of outside data to the watershed.

The assumption of the proportionality of damage to excess magnitude is, of course, unsupported by anything except judgment. But some fundamental relationship must be assumed, and unless there is good reason to assume otherwise, the simplest acceptable relationship is the one to use.

This assumption is admittedly much oversimplified because the true relationship is very complex, involving energy relationships, etc. After thinking the matter over, I can recognize both plus and negative influences, but cannot evaluate them. I believe it is within the limits of accuracy of our other data to accept the direct proportionality until we progress to the point where we can propose and justify something better.

I can see how, in this particular case, from the mathematics of the situation (accepting line A as a straight line) the line B-C (which represents the damage frequency ratio on semi-logarithmic paper) becomes a straight line passing through the 100% point and the two-year zero percentage point. It means that damage is directly proportional to the excess of storm magnitude over that corresponding to a two-year storm.

peak flood flow, which might better be the basis for frequency
 for considering downstream consequences.
 By virtue of the fact that both the hydrologic elements
 and the damage figures for the 1958 season are localized for the
 San Gabriel, the analysis is pointed directly at the San Gabriel,
 and is not a translation of outside data to the watershed.
 The assumption of the proportionality of damage to excess
 magnitude is, of course, unsupported by anything except judgment.
 But some fundamental relationship must be assumed, and unless
 there is good reason to assume otherwise, the simplest accept-
 able relationship is the one we use.
 This assumption is admittedly much oversimplified because
 the true relationship is very complex, involving energy relation-
 ships, etc. After thinking the matter over, I am convinced
 both plus and negative influences, but cannot evaluate them.
 I believe it is within the limits of accuracy of our other data
 to accept the direct proportionality until we progress to the
 point where we can propose and justify something better.
 I can see how, in this particular case, from the mathematics
 of the situation (assuming line A as a straight line) the line
 B-C (which represents the damage frequency ratio on semi-logarithmic
 paper) becomes a straight line passing through the 1958 point and
 the two-year return percentage point. It means that damage is
 directly proportional to the excess of storm magnitude over that
 corresponding to a two-year storm.

The next item is the question of the "Duration Method" vs. the "California Method." I am informed that all the hydrologic data taken from the Army were developed by the "duration method." It seems to me logical to carry the analysis through to completion on that basis. Therefore, I would use the thirty-three year or "duration method" frequency for the 1938 storm just as has been done.

I recognize that by the "duration method", we get values which represent the minimum flood to be expected (W.S. Paper 771, page 60, paragraph 2) whereas by the same reference, the "California method" would give values representing the probable (or average) value, which is greater.

I believe it would have been better to have used the "California method" from the beginning. The data we used was prepared by the Army, which is interested in determining the value below which they should not go and to which they must add an appropriate factor of safety. We are more interested in the probable or average value, as developed by the "California method."

However, the amount of work already done on the basis of the present analysis is so great that to substitute new damage ratios would involve a prohibitive amount of time. If an unacceptable principle or basic relationship had been employed, there would be no choice but to make a change. In this case, there is merely a difference of opinion as to detail of method -

The next item is the question of the "Transition Method".
 as the "California Method". I am informed that all the hydro-
 logic data taken from the Army were developed by the "Transition
 method". It seems to me logical to carry the analysis through
 to completion on that basis. Therefore, I would use the thirty-
 three year or "Transition method" frequency for the 1938 return
 just as has been done.

I recognize that by the "Transition method", we get values
 which represent the minimum flood to be expected (W.C. Paper 77)
 page 60, paragraph 2) whereas by the same reference, the
 "California method" would give values representing the probable
 (or average) value, which is greater.

I believe it would have been better to have used the
 "California method" from the beginning. The data we used was
 prepared by the Army, which is interested in determining the
 value below which they should not go and to which they must add
 an appropriate factor of safety. We are more interested in the
 probable or average value, as developed by the "California method".

However, the amount of work already done on the basis of
 the present analysis is so great that to substitute new design
 ratios would involve a prohibitive amount of time. If an un-
 acceptable principle or basis relationship had been employed,
 there would be no choice but to make a change. In this case,
 there is merely a difference of opinion as to detail of method.

with support for both viewpoints. Therefore, I do not propose a change at this late date.

A generalized or overall check analysis has been made for me to show about what the resulting change in the watershed damage ratio factor would be if the "California method" had been used from the beginning, and it appears that instead of being 8.05, it would be about 9.85, which would mean an increase of about 20%, which means that the proposed damage ratios will be on the conservative side and tend to minimize damages.

Consideration can be given to this fact when applying judgment later in the economic analysis on points where alternatives are presented and judgment is required. The damage ratios, as developed, should be clearly recognized as indicating minimum conditions which are expected to be "equalled or exceeded," and not average conditions.

I believe that the rational solution represented by the proposed damage ratios is sounder than one based on the available historical flood damages. The only damage estimate made use of in the existing analysis is that for 1938. We know just about how good that is, and the conditions under which it was developed.

On the other hand, some of the damage estimates prepared by Mr. King are necessarily of uncertain original dependability and coverage. Others were taken at times so remote that large compensatory adjustments are necessary for physical and economic

with support for both viewpoints. Therefore, I do not pro-
pose a change at this time.

A generalized or overall check analysis has been made
for us to show about what the resulting change in the water-
damage ratio factor would be if the "deliberate method" had
been used from the beginning, and it appears that instead of
being 3.05, it would be about 2.65, which would mean an increase
of about 20%, which means that the proposed damage ratios will
be on the conservative side and tend to minimize damages.

Consideration can be given to this fact when applying
judgment later in the economic analysis on points where either
ratios are presented and judgment is required. The damage
ratios, as developed, should be closely watched as indicating
minimum conditions which are expected to be "equalled or exceeded,"
and not average conditions.

I believe that the rational solution represented by the
proposed damage ratios is nearer than one based on the available
historical flood damages. The only damage estimates made use of
in the existing analysis is that for 1938. We know just about
how good that is, and the conditions under which it was developed.

On the other hand, some of the damage estimates prepared
by Mr. King are necessarily of uncertain original dependability
and average. Others were taken at times so remote that large
operational adjustments are necessary for physical and economic

changes. We do not know the frequency based on the three hydrologic factors. The number of instances is small. These and other factors make no question the use of the data except for a check.

Some method might be developed for utilizing such historical data, but at the present moment, I do not feel able to use it with as much confidence as I can the basic physical data used in the rational method. I do not think that a satisfactory formula can be worked out for use of the historical data as the sole basis for the hydrologic factor, without spending much time on additional study and greatly delaying the report.

The ratio for San Gabriel is 8.05, as against 6.9 for the Los Angeles. This is consistent with a 1938 storm frequency of 33 years in the San Gabriel, as against 40 years in the Los Angeles. Furthermore, the analysis for the San Gabriel gives somewhat greater consideration to the smaller or high frequency storms which collectively add considerable to the type of flood damage with which we are concerned, namely, on agricultural lands.

I am not satisfied with the proposed solution, but know that we will never be fully satisfied. I think the San Gabriel is at least one step further toward perfection than the Los Angeles. I can see no justification for changing it at this time.

J. F. Johnston

July 17, 1940

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hydrologic factors. The number of instances is small. These
and other factors make me question the use of the data except
for a check.
Some method might be developed for utilizing such his-
torical data, but at the present moment, I do not feel able
to use it with as much confidence as I can the basic physical
data used in the rational method. I do not think that a ratio-
factor formula can be worked out for use of the historical
data as the sole basis for the hydrologic factor, without
expending much time on additional study and greatly delaying
the report.
The ratio for San Gabriel is 8.05, as against 6.9 for the
Los Angeles. This is consistent with a 1938 storm frequency
of 35 years in the San Gabriel, as against 10 years in the Los
Angeles. Furthermore, the analysis for the San Gabriel gives
numbers greater consideration to the smaller or high frequency
storms which collectively add considerable to the type of flood
damage with which we are concerned, namely, an agricultural lands.
I am not satisfied with the proposed solution, but know
that we will never be fully satisfied. I think the San Gabriel
has a great one step further toward perfection than the Los
Angeles. I can see no justification for changing it at this time.

L. E. Johnson

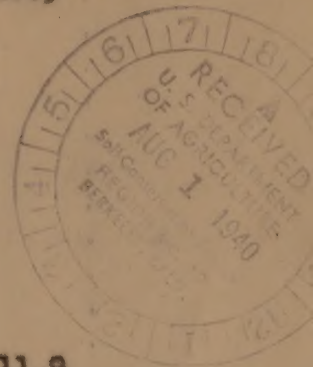
July 17, 1940

Table No. H-4

May 23, 1940

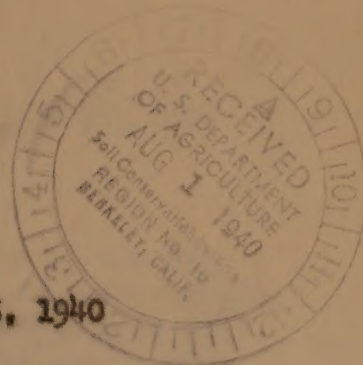
The Frequency of the 1938 Storm for Subareas
of the San Gabriel Watershed and the Ratio of Erosion
Magnitude Potentials of 50-years of Future
Storms to that of the 1938 Storm

Food Source	:Area in:	Frequency of March 2, 1938 Storm				:Ratio of total 50-yr
as & Sub-	:Sq.Mi.	:Based on:	:Based on:	:Based on:	:Based on av-	:Erosion Magnitude to
as	:	:total	:24-hour	:Max.1-hr:	:erage of 3	:1938 Storm Erosion Mag-
:	:	:rainfall:	:rainfall:	:rainfall:	:factors	:nitude
1	2	3	4	5	6	7
<u>Mountain Area</u>						
<u>Area No. 1</u>						
Area "A"	40.42	54	22	3	26	11.1
Area "B"	161.58	75	29	3	36	9.9
Area "C"	8.80	98	15	1	38	9.7
Area "D"-1	15.11	98	15	1	38	9.7
<u>Area No. 2</u>						
Area "C"	4.49	98	15	1	38	9.7
Area "F"	15.92	98	15	1	38	9.7
Area "I"	2.30	70	13	1	28	10.9
<u>Valley Area</u>						
<u>Area No. 1</u>						
Area "D"-2	10.15	70	13	1	28	
<u>Area No. 2</u>						
Area "A"	3.30	98	15	1	38	11.9
Area "B"	8.41	70	13	1	28	
Area "D"	2.73	70	13	1	28	
Area "E"	9.25	70	13	1	28	
Area "G"	2.57	70	13	1	28	
Area "H"	7.81	46	7	1	18	
Area "J"	12.34	70	13	1	28	
Area "K"	26.23	46	7	1	18	
Area "L"	6.18	46	7	1	18	
Area "M"	2.18	46	7	1	18	
Area "N"	12.36	46	7	1	18	
<u>Area No. 3</u>						
Area "A"	3.91	70	13	1	28	13.0
Area "B"	80.23	46	7	1	18	
<u>Area No. 4</u>						
Area "A"	23.40	54	7	1	21	9.04
Area "B"	17.90	39	8	1	16	
Area "C"	2.05	150	14	1	55	
Area "D"	3.05	150	14	1	55	
Area "E"-1	37.00	150	14	1	55	
Area "E"-2	98.84	100	18	1	40	
<u>Area No. 5</u>						
Fire Area	84.70	100	18	1	40	9.6
Total Area	703.21	Average for Watershed:			32.68	



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UNITED STATES DEPARTMENT OF AGRICULTURE
Bureau of Agricultural Economics
222 Mercantile Building
Berkeley, California



July 15, 1940

MEMORANDUM

TO: Mr. C. J. Kraebel, Chairman, Field Working Committees 18 & 20

FROM: Mr. Leonard M. Hill, Agricultural Economist

SUBJECT: Alternative Proposals for Hydrologic Analyses for the San Gabriel Flood Control Survey Report.

After reviewing the hydrologic analyses presented by Mr. W. C. Barrett and the comments thereon by Mr. R. S. Goodridge, the following observations are made:

1. I have no comment to offer on the relative merits of the alternatives proposed by Mr. Goodridge and Mr. Barrett with respect to the derivation of storm magnitudes and frequencies. This is a matter wholly outside the field of our bureau and we must therefore rely upon the physical scientists.

2. With regard to the relation of damage to storm magnitude, it appears doubtful that Mr. Barrett has submitted substantiating evidence to sustain his contention that the damage curve will be the same shape as the storm curve. It is my impression and that of Mr. F. D. Duncan, our Damage Appraiser, that for most watersheds this relationship does not hold in that proportionately higher damages result from higher floods. If the southern California streams are unique in this respect, then it would appear necessary to obtain substantiating data. We question the reliability of the damage information compiled by Dr. King and used by Mr. Goodridge in his analysis, but the fact that it supports his prior argument would lend weight to its acceptance.

I realize that we must make a decision in this matter at a very early date, and therefore hesitate to propose additional investigation. However, it is the feeling of Mr. Duncan and myself that if Mr. Barrett's results are to be utilized they should be supported by more adequate data. It is believed that a sample check of damages sustained in storms other than the 1938 storm could be made within a reasonable time. By assembling such

UNITED STATES DEPARTMENT OF AGRICULTURE
Bureau of Agricultural Economics
222 West Main Building
Berkeley, California

July 15, 1940

MEMORANDUM

TO: Mr. G. J. Knebel, Chairman, Flood Working Committee 18 & 20

FROM: Mr. Leonard M. Hill, Agricultural Economist

SUBJECT: Alternative Proposals for Hydrologic Analyses for the San Gabriel Flood Control Survey Report.

After reviewing the hydrologic analyses presented by Mr. W. C. Barrett and the comments thereon by Mr. R. S. Goodridge, the following observations are made:

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July 15, 1940

data a ratio could be worked out which would be applicable to the San Gabriel watershed as a whole. I realize that information is very scarce on the damages for other than the 1938 flood, but think it would be well to see what could be done in this direction. It is my impression that damages from the 1934 storm were compiled for the San Jose tributary and analyses of this data might well give some significant results in establishing a sound storm-damage relationship.

Penciled comments by GJK:

1st Indorsement:

I am inclined to agree with Hill. In our meeting in Glendora we discussed the advisability of drawing into consideration flood damages from storms other than that of March 1938. Main objections seemed to be the delay involved and also the sketchiness of such data. There are some such data however, and it seems only reasonable that they be used for what they are worth - they should, in fact, have been drawn in from the very first. Another point is that different parts of the watershed, due to different values and intensity of developments affected by floods, may have very different ratings of flood damage hazard. If this is true the hydrological discussion and calculations should take account of it.

C. J. Kraebel



July 15, 1940

- 2 -

Memo to Mr. Knebel

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Enclosed comments by CLK:

Let Informants:

I am inclined to agree with Bill. In our meeting in Glenahorn we discussed the advisability of drawing into consideration flood damages from storms other than that of March 1938. Main objections seemed to be the delay involved and also the sketchiness of such data. There are some such data however, and it seems only reasonable that they be used for what they are worth - they should, in fact, have been drawn in from the very first. Another point is that different parts of the watershed, due to different values and intensity of developments affected by floods, may have very different ratings of flood damage hazard. If this is true the hydrological discussion and calculations should take account of it.

C. J. Knebel



San Francisco, California
July 24, 1940



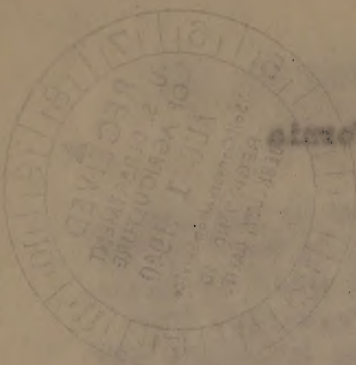
MEMORANDUM FOR JOHN H. LAWRENCE

I have reviewed Chap. IV. Hydrology of the San Gabriel Watershed and vicinity of the San Gabriel River report. Pages 1 to 22 incl. deal with meteorology, rainfall, and runoff as related to both the San Gabriel watershed and southern California. The remainder of the text, pages 23 to 44, pertain to the development of the hydrology as a basis for the allocation of potential storm damages. This memorandum will be confined to a discussion of the latter part.

The same general conditions appear to exist as in the case of the Los Angeles River basin with respect to records of floods, runoff, rainfall, and flood damages, etc. Consequently, it is to be assumed that the premise for the determination of probable future damages should be similar to the procedure worked out in the Los Angeles River report. With certain modifications I believe that procedure gives a reasonable evaluation beyond which attempted refinements would appear to be unwarranted by the conditions.

In the present study I feel there should be attempted a correlation of damages, by classes of storms, against the discharge hydrograph, by way of substantiation if possible.

There is a 44 year record available on the San Gabriel River at Azusa representative of the entire watershed; and representative of smaller tributaries there are Fish Creek, Rogers Crk, Sawpit Crk, San Dimas



San Francisco, California
July 24, 1940

MEMORANDUM FOR JOHN E. LAMBERT

I have reviewed Chap. IV, Hydrology of the San Gabriel Watershed and vicinity of the San Gabriel River report. Pages 1 to 32 incl. deal with meteorology, rainfall, and runoff as related to both the San Gabriel watershed and southern California. The remainder of the text, pages 33 to 44, pertain to the development of the hydrology as a basis for the allocation of potential storm damages. This memorandum will be confined to a discussion of the latter part.

The same general conditions appear to exist as in the case of the Los Angeles River basin with respect to records of floods, runoff, rainfall, and flood damage, etc. Consequently, it is to be assumed that the basis for the determination of probable future damages should be similar to the procedure worked out in the Los Angeles River report. With certain modifications I believe that procedure gives a reasonable evaluation beyond which attempted refinements would appear to be unwarranted by the conditions.

In the present study I feel there should be attempted a correlation of damage, by classes of storm, against the historical hydrograph, by way of substantiation if possible.

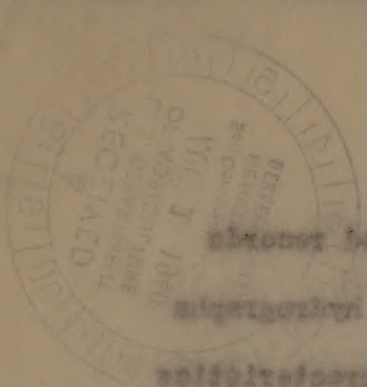
There is a 44 year record available on the San Gabriel River at

Atmos representative of the entire watershed; and representative of smaller tributaries there are Fish Creek, Rogers Crk., Rabbit Crk., San Diego

Creek, etc. all with records exceeding 20 years. Where flood records do not exist for one reason or another, it is possible that hydrographs could be built up using the formula $Q = CQ^n$, based on the characteristics of known floods.

In talking with Mr. Tanner toward the conclusion of the writing of the Los Angeles report he spoke of working on this phase, but I find the only reference made by Mr. Barrett is on page 25, where the reason for not using it is given as due to the absence of storm damages data excepting for that of 1938.

The procedure for determining the frequency of the 1938 storm for the entire watershed and the several sub-areas, is similar to that used in the Los Angeles River report. It is based upon the Corps of Engineers' rainfall intensity curves for 24 hour and total rainfall. I endorse it in principle but believe the method should be reviewed with the object of adjusting the differences, if appreciable, obtaining from the use of the "duration" method as used by the Corps of Engineers in developing the maximum day rainfall frequencies. As I have not checked Mr. Goodwages' calculations I cannot say he is correct, but in view of the difference in data used and the plotting points some adjustment in the 1938 storm frequency would be expected. It may be that Mr. Barrett has already checked the Army curves and found that the differences are insignificant and consequently, elected to use them. In the use of the Los Angeles report the adjustment is stated to have been made. Mr. Barrett's determination of a 33 years frequency for the San Gabriel watershed as a whole appears reasonable compared to that for the Los Angeles River established at 40 years. Referring to Table H-1, items 2 to 9 incl. I believe the



...with records extending 30 years. ...
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could be built up using the formula $P = 0.97$ based on the characteristics
of known floods.

In talking with Mr. Tamm, toward the conclusion of the writing

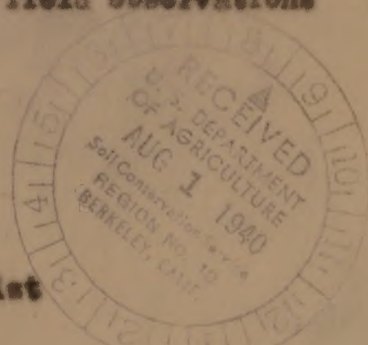
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The procedure for determining the frequency of the 1938 storm for
the entire watershed and the several sub-areas, is similar to that used
in the Los Angeles River report. It is based upon the Corps of Engineers'
rainfall intensity curves for 24 hour and total rainfall. I believe it
is probable but believe the method should be reviewed with the object
of adjusting the differences, if considerable, obtained from the use of
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the maximum day rainfall frequency. As I have not checked Mr. Barrett's
calculations I cannot say he is correct, but in view of the difference
in data used and the shifting points some adjustment in the 1938 storm
frequency would be expected. It may be that Mr. Barrett has already
checked the Army curves and found that the differences are insignificant
and consequently, elected to use them. In the case of the Los Angeles
report the adjustment is stated to have been made. Mr. Barrett's deter-
mination of a 75 years frequency for the San Gabriel watershed as a whole
appears reasonable compared to that for the Los Angeles River established
at 50 years. Referring to Table B-1, Item 2 on p. 10, I believe the

average frequency amounts to 32.5 instead of 32.68 as given, but still about once in 33 years as stated in the text.

After studying the procedure and method for relating storm frequency, magnitude, and damage, as outlined on pages 36 to 44 incl. and Chart H-5, I am inclined to think that little, if any, improvement has been made over the direct assumptions made in the Los Angeles River report. In fact the basic assumption as stated on pages 39 and 40 are largely without substantiation, particularly item 3. Further, curve B-C on Chart H-5 which relates the storm frequencies directly to percent damage, appears to be assumed as a straight line between 2 years at 50% and 50 years at 100%, in effect assuming a logarithmic variation which may or may not be true. Together, this entire procedure is based on assumptions treated mathematically, but without basis in fact. Considering the data available it is my opinion that the assumptions as stated in the Los Angeles River report, relating the three classes of storms equally as groups, is clear-cut and definite. It can be substantiated by judgment and reason if not by fact. Incidentally, I believe the wording in this relation as given in the Los Angeles River report should be revised to eliminate the reference to a pleasant mental picture. In applying the Los Angeles method to the present study, necessary revisions should be made, of course, in accordance with additional data and information available. Such items as storms down to 2 year frequencies as class one storms if justified by field observations should certainly be included.

NICK F. MEADOWCROFT
Assoc. Conservationist



89810

average frequency amounts to 32.5 instead of 32.68 as given, but still

about once in 37 years as stated in the text.

After studying the procedure and noting the relating state frequency,

magnitudes, and damage, as outlined on pages 36 to 39 incl. and Chart B-2,

I am inclined to think that little, if any, improvement has been made over

the direct assumptions made in the Los Angeles River report. In fact the

basic assumptions as stated on pages 39 and 40 are largely without sub-

stantiation, particularly item 2. Further, curve B-2 on Chart B-2 which

relates to the return frequencies directly to percent damage, appears to be

assumed as a straight line between 2 years of 30% and 50 years at 100%.

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WILL E. HANCOCK
Asst. Commissioner

89810



IV. HYDROLOGY OF THE SAN GABRIEL WATERSHED AND VICINITY

Meteorology

Generally no rain falls between the last of April and the first of October. At Los Angeles, which is representative of the plains area of the San Gabriel Watershed, 60 years of records show that out of a mean annual rainfall of 15.2 inches, 11.8 inches fell between December 1 and March 30, or 77 percent. Minimum and maximum temperatures are around 52° and 73° respectively, with the average temperature through the rainy season ranging around 56°. The average percent of sunshine for the year is 72 percent and varies from a minimum monthly of 63 percent for June to a maximum of 79% for September.

Unirrigated or natural annual plants and grasses begin to grow in November, growing more or less prolifically until April. By May the dry season is being reflected in the drying up of this natural vegetation, but extensive irrigation in the valley lands carried on through the summer keeps these lands in vigorous production.

The average wind velocity varies from only 4.6 to 5.5 miles per hour. From February to October the prevailing wind is from the west. These facts indicate the prevalence of a remarkably mild and equable climate, which has been and will continue to be a major factor in the development of the watershed.



Hydrology

IV. HYDROLOGY OF THE SAN GABRIEL WATERSHED AND VICINITY

Hydrology

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The Origin and Nature of Rain Storms
in the Los Angeles Vicinity

The storms that are almost entirely responsible for general floods in the Los Angeles River Watershed are those originating on, or passing over, the North Pacific Ocean. An admirable discussion of the origin, movement and significance of storms of this type has been given in a recent report of the "Hydrology of the Los Angeles Drainage Area," by the United States Engineer Office of Los Angeles, as follows:

"The usually prevailing west to east circulation causes a preponderance of maritime air masses from the vast area of the Pacific Ocean to invade the region. Thus, the types of air masses that are associated with frontal disturbances in southern California consist of Polar Pacific and Tropical Pacific air. Tropical Pacific air originates at about 20° - 30° north latitude, on the southern boundary of the semi-permanent Pacific anti-cyclone. Southern California does not come under the influence of this type of air when the high pressure area is centered in its usual position, owing to the prevailing winds. However, if the north Pacific anti-cyclone breaks down, or if a migratory Aleutian cyclone and an associated Polar front move far enough southward, an inland flow of Tropical Pacific air will occur. This air, as contrasted to Polar Pacific air, has higher temperatures and specific humidity, the water vapor content being much greater, level for level. There are two types of Polar Pacific air that occur, one type which emanates from the Gulf of Alaska in the vicinity of the Aleutian Islands, and the other which is of Siberian origin. During the summer, the water surfaces have a relatively cooling effect, and the Polar Pacific air, after a southerly passage over the ocean, reaches southern California in a very stable state. The higher topography of the land is the only means of lifting this air, which has too low a relative humidity to cause precipitation. In the winter season, however, Polar Pacific air is the cause of the major part of the precipitation in southern California. The Polar Pacific air of Siberian origin, which has had a four-to-six-day trajectory over the Pacific Ocean, is the most important type to be considered in connection with the worst probable meteorological conditions. Owing to its prolonged passage over the warm water surface of the ocean, the Polar Siberian air is enabled thereby to absorb moisture and warmth to a high elevation while remaining cold and humid in its upper most strata. This condition is indicative of a very convectively unstable air mass, and, since it contains a large amount of water vapor, any lifting will cause intense precipitation. The synoptic

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situation that is conducive to bringing this type of air to southern California is that in which the Polar Pacific front (discontinuity surface between Polar Pacific air on the north side and Tropical Pacific air on the south side) is displaced by the southward movement of the Polar Siberian and north Pacific anticyclones, which are semipermanent features of the atmospheric circulation. Cyclonic wave disturbances, which generally occur as an occluded type of discontinuity, are formed on this displaced frontal system, and are then induced to move directly across the southern California area. When this occlusion, having very convectively unstable Polar Siberian air in the active cold wedge underlying moist Tropical Pacific air aloft, is deflected upward by the permanent front that is formed by the ascending slopes of the Santa Monica Mountains and the precipitous Sierra Madre Mountains, exceedingly high rainfall intensities result. Although precipitation in southern California may be caused by the other general types of surface discontinuity disturbances, this synoptic situation is the one which approximated the worst probable meteorological condition. The approach of the cyclonic wave disturbances may be in a path from southeast through south, and west to northwest. There may be several successive waves of varying duration and intensities." 1/

1/ Report by United States Engineer Office, "Hydrology in the Los Angeles County Drainage Area - March 1939," pages 18, 23, and 24.

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Report by United States Engineer Office, "Hydrology in the Los Angeles County Drainage Area - March 1939," pages 18, 23, and 24.

The report describes the hydrology of the Los Angeles County Drainage Area, including the Santa Monica Mountains and the Sierra Madre Mountains. It discusses the various types of weather systems that can affect the area, including cyclonic wave disturbances, and the resulting precipitation. The report also discusses the impact of these weather systems on the local climate and the need for flood control measures.

It should be noted that the discussion just given refers to the meteorological conditions which were the cause of the March 1938 storm and which are of the type of phenomena that are expected to produce even greater storms. It is equally of great importance, however, in a program of watershed improvement, to note at least three other types of storms that occur in Southern California.

Mr. Dean Blake ^{2/}, separates storms according to their genesis into four groups. They are:

North Pacific Type

This group ties in naturally with the recognized and fundamental types set forth by Thomas R. Reed. ^{3/} As he states, his westerly types which may be associated with the North Pacific type of this paper, and have the same characteristics "run well to the south on many occasions" and when their paths are more southerly than usual, Southern California is found within the precipitation area. This type is responsible for most of the rainy days, the largest falls, and the greatest number of days of any given intensity."

"The general trend of the northerly storm tracks is southward with the approach of winter, but not until November is Southern California within the precipitation area. The amount of precipitation and the number of days with rain increases until the maximum is reached in January after which, with the return northward of the storm paths, both become less and end completely in May. It is worthy of note that days with rain are equally frequent from February to May, while the catch falls off materially,

^{2/} Storm types and Resultant Precipitation in the San Diego Area, Dean Blake, U.S. Weather Bureau, San Diego, Cal.

^{3/} Weather Types of the Northeast Pacific Ocean as related to the Weather of the North Pacific Coast. T. R. Reed, Monthly Weather Review, December 1932, Vol. 60, pp. 246-252.

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Storm types and resultant precipitation in the San Diego area, Dean

Blake, U.S. Weather Bureau, San Diego, Cal.

Weather types of the Northwest Pacific Ocean as related to the
Weather of the North Pacific Coast. T. R. Reed, Monthly Weather
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denoting a decrease in energy rather than in the number of storms. This type appears to be the most dependable of the four. Large excesses and deficiencies in seasonal totals seem to be due more often to an unusual number of storms of the other types rather than to wide variations in the north Pacific group." It would seem that the March storm of 1938 was substantially of this type.

South Pacific Type

Quoting Mr. Reed, Mr. Blake states:

"Lows of like origin (North Pacific) sometimes form over the Southern California coast on the tropical side of an overrunning southwest high, or they may lodge there after running south along the eastern flank of a north-south high which, after their passage, presses inland over the Pacific Northwest in a quasi-enveloping movement.

Lows of this nature are responsible in the main for storms classified under the south Pacific type. At times, though, disturbances that are associated with Reed's southerly type take the form of a trough, and lie near enough to the coast to bring San Diego County under the domination of the secondary depressions that form in the lower end of the trough. This group is also classified under the South Pacific type.

The appearance of storms in this area is haphazard, and wide variations in number and rainfall amounts are found, but apparently conditions are most favorable for their formation during January, as they have proved to be the best rain producers during that month of any of the four types. They develop from November to March, move quickly, travel singly, and produce warm and not infrequently very heavy rains, particularly at stations where the mountain ranges parallel the coast."

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South Pacific Type

Quoting Mr. Reed, Mr. Blake states:

"Lows of like origin (North Pacific) sometimes form over the Southern California coast on the tropical side of an overrunning south-west high, or they may lodge there after running south along the east-ern flank of a north-south high which, after their passage, presses inland over the Pacific Northwest in a quasi-enveloping movement. Lows of this nature are responsible in the main for storms classified under the south Pacific type. At times, though, disturbances that are associated with Reed's southerly type take the form of a trough, and lie near enough to the coast to bring San Diego County under the domination of the secondary depressions that form in the lower end of the trough. This group is also classified under the South Pacific type. The appearance of storms in this area is haphazard, and wide variations in number and rainfall amounts are found, but apparently conditions are most favorable for their formation during January, as they have proved to be the best rain producers during that month of any of the four types. They develop from November to March, move quickly, travel singly, and produce rain and not infrequently very heavy rains, particularly at stations where the mountain ranges parallel the coast."

Interior Type

"By far the most interesting and complicated disturbances are of the Interior type. Storms of this nature correspond to those which are the result of Reed's northerly type. While their breeding place appears to be the Great Basin most of the time, nevertheless they develop anywhere over the far western Interior. Their growth and subsequent movements are erratic and hard to predict with any great degree of accuracy. Before the last decade the temptation was to ignore them as potential heavy rain producers. Tabulations of rainfall show that in San Diego County 32 percent of the total number of rainy days and about 30 percent of the precipitation resulted from storms assignable to this type, and that 24-hour amounts greater than 1" were frequent. Because of the large high pressure area over the ocean off the coast of California at the time these lows form, too little weight usually is given to the drop in barometer that precedes their genesis, and before we are aware of it, general, and in many cases, heavy rain has begun over all of southern California. While Interior storms are most active from February to May, they may form in any month of the year. During the last 5 years, (1929-33) however, none was tabulated during July or January."

Mexican Type

"The fourth and last, the Mexican type, is responsible for only a small percent of the whole number, but the amounts of their precipitation at Cuyamaca and Warner Springs are much greater than at San Diego, and add materially to the season's totals. Only occasionally do they cross San Diego County. They originate in the tropics south and west of Baja California, and move northward, and only through chance radio

Interior Type

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reports from ships that happen to be in their path are we able to follow them. Occurring at a time when fruits and grapes are ripening or drying, they always are most unwelcome. Torrential rains often are the result, at which times damage to property is great, railways and highways suffering heavily. An example of particularly destructive rains of this type was the storm in the Tehachapi Mountains of September 28 to October 1, 1932, where the loss of life was 15 and the damage was estimated to be over \$1,000,000. ^{3/} Fortunately they are limited to the period from August to November, and years have passed without one of serious proportions reaching this part of the State.

A summary of the total number of days with rain from each type at stations in Southern California for the years 1929 to 1933 is given in table Hyd. 1.

^{3/} Destructive rains in the Tehachapi Mountains, Kern county, Calif. M. Sprague, in October 1932 Climatological Data, California section.

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A summary of the total number of days with rain from each type at stations in Southern California for the years 1929 to 1933 is given in Table No. 1.

The first type of rain, the light drizzle variety, is given in the first column of the table. This type of rain is common throughout the State, and before we are aware of it, it is falling. It is very common, heavy rain has been over all of Southern California. This light rain is most common from February to May, but may come at any time of the year. During the last 5 years, (1929-33) there was more than doubled during July or January.

The second type of rain, the heavy rain, is responsible for only a small percent of the whole number, but the amount of their weight is as great as the light rain and much greater than the first.

✓ Destructive rains in the Tehachian Mountains, Kern County, Calif. N. Sprague, in October 1932 Climatological Data, California section.

TABLE HYD. 1

Total number of days with rain from each type at San Diego, and total amounts from each type at San Diego, Cuyamaca, Warner Springs, during the last five seasons. ^{1/} (1929 to 1933)

Month	North Pacific				South Pacific			
	San Diego	Cuyamaca	Warner	San Diego	Cuyamaca	Warner		
	Days	Amts	Amts	Amts	Days	Amts	Amts	Amts
	Inches	Inches	Inches	Inches	Inches	Inches	Inches	Inches
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
July	0	0	0	0	0	0	0	0
August	0	0	0	0	0	0	0	0
September	0	0	0	0	0	0	0	0
October	0	0	0	0	0	0	0	0
November	10	1.66	5.26	2.02	3	.37	1.03	.51
December	17	5.85	22.97	6.78	5	1.68	2.97	1.52
January	39	11.83	30.04	11.40	7	2.46	13.63	6.08
February	11	2.05	13.45	4.62	11	5.77	13.68	8.40
March	9	1.40	5.29	1.87	3	1.34	2.09	.51
April	10	.96	7.99	3.32	0	0	0	0
May	10	.84	5.51	1.35	0	0	0	0
June	0	0	0	0	0	0	0	0
Totals	106	24.59	90.51	31.36	29	10.62	33.40	17.02

Month	Interior				Mexican			
	San Diego	Cuyamaca	Warner	San Diego	Cuyamaca	Warner		
	Days	Amts	Amts	Amts	Days	Amts	Amts	Amts
	Inches	Inches	Inches	Inches	Inches	Inches	Inches	Inches
(10)	(11)	(12)	(13)	(14)	(15)	(16)	(17)	(18)
July	0	0	0	0	0	0	1.24	0.38
August	4	.08	0	0	2	.03	3.03	5.17
September	1	.04	.05	.01	2	.22	5.30	1.94
October	3	.41	3.52	2.01	2	1.10	5.52	2.95
November	6	1.11	6.35	2.60	2	.78	.63	.41
December	3	.85	7.72	3.21	0	0	0	0
January	0	0	0	0	0	0	0	0
February	10	3.26	11.04	6.69	0	0	0	0
March	14	3.11	7.65	3.99	0	0	0	0
April	13	4.30	12.07	4.03	0	0	0	0
May	10	1.80	9.43	5.26	0	0	0	0
June	4	.12	.16	.06	0	0	.08	0
Totals	68	15.08	57.99	27.86	8	2.13	15.80	10.85

^{1/} "Storm Types and Resultant Precipitation in the San Diego Area"
by Dean Blake.

TABLE HYD. 1

total number of days with rain from each type at San Diego, and total amounts from each type at San Diego, Warner Springs, Warner Springs, during the last five seasons. (1929 to 1933)

Month	North Pacific						South Pacific					
	San Diego : Warner : Days : Inches	San Diego : Warner : Days : Inches	San Diego : Warner : Days : Inches	San Diego : Warner : Days : Inches	San Diego : Warner : Days : Inches	San Diego : Warner : Days : Inches	San Diego : Warner : Days : Inches	San Diego : Warner : Days : Inches	San Diego : Warner : Days : Inches	San Diego : Warner : Days : Inches	San Diego : Warner : Days : Inches	San Diego : Warner : Days : Inches
July	0	0	0	0	0	0	0	0	0	0	0	0
August	0	0	0	0	0	0	0	0	0	0	0	0
September	0	0	0	0	0	0	0	0	0	0	0	0
October	0	0	0	0	0	0	0	0	0	0	0	0
November	10	1.66	2.85	11.40	1.45	1.87	10	1.03	1.66	2.85	11.40	1.45
December	17	2.85	30.04	1.45	1.87	1.87	17	2.85	30.04	1.45	1.87	1.87
January	39	11.85	13.45	1.45	1.87	1.87	39	11.85	13.45	1.45	1.87	1.87
February	11	2.05	1.45	1.45	1.87	1.87	11	2.05	1.45	1.45	1.87	1.87
March	9	1.40	2.29	1.45	1.87	1.87	9	1.40	2.29	1.45	1.87	1.87
April	10	.96	7.99	1.45	1.87	1.87	10	.96	7.99	1.45	1.87	1.87
May	10	.84	5.51	1.45	1.87	1.87	10	.84	5.51	1.45	1.87	1.87
June	0	0	0	0	0	0	0	0	0	0	0	0
Totals	106	24.59	99.51	31.36	39	39	106	24.59	99.51	31.36	39	39
Month	Interior						Mexican					
	San Diego : Warner : Days : Inches	San Diego : Warner : Days : Inches	San Diego : Warner : Days : Inches	San Diego : Warner : Days : Inches	San Diego : Warner : Days : Inches	San Diego : Warner : Days : Inches	San Diego : Warner : Days : Inches	San Diego : Warner : Days : Inches	San Diego : Warner : Days : Inches	San Diego : Warner : Days : Inches	San Diego : Warner : Days : Inches	San Diego : Warner : Days : Inches
July	0	0	0	0	0	0	0	0	0	0	0	0
August	4	.08	0	0	0	0	4	.08	0	0	0	0
September	1	.04	.05	.01	2.01	2.01	1	.04	.05	.01	2.01	2.01
October	3	.41	3.52	2.60	2.60	2.60	3	.41	3.52	2.60	2.60	2.60
November	6	1.11	6.35	3.21	3.21	3.21	6	1.11	6.35	3.21	3.21	3.21
December	3	.85	7.75	0	0	0	3	.85	7.75	0	0	0
January	0	0	0	0	0	0	0	0	0	0	0	0
February	10	3.26	11.04	6.69	3.99	3.99	10	3.26	11.04	6.69	3.99	3.99
March	14	3.11	7.65	4.03	5.26	5.26	14	3.11	7.65	4.03	5.26	5.26
April	13	4.30	12.07	5.26	5.26	5.26	13	4.30	12.07	5.26	5.26	5.26
May	10	1.80	9.43	0	0	0	10	1.80	9.43	0	0	0
June	4	.12	1.6	0	0	0	4	.12	1.6	0	0	0
Totals	68	15.08	57.99	27.86	8	8	68	15.08	57.99	27.86	8	8

"Storm Types and Resultant Precipitation in the San Diego Area"
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RAINFALL

Hydrology
April 2-1940

(Typed 4-10-40)

Rainfall Records:

A good summary of rainfall recordings in Los Angeles County has been given by the U.S.E.D. in their report of September, 1939, on "Flood Control for the Los Angeles Drainage Area". It states as follows:

"There are no continuous rainfall records in the Los Angeles County Drainage Area prior to 1877. From 1877 to 1917, the records pertain to the coastal plain, valley and foothill stations with the exception of the records of Echo Mountain, Colby Ranch, and Mount Wilson, which have been kept since 1895, 1897, and 1904, respectively. Since 1917, the number of stations has been greatly increased, so that, at present, observations are being made regularly at about 300 stations, of which 125 are in the mountainous area. Monthly records are available for all of the stations, daily records for a great majority, and at 59 stations automatic rain gages have been installed having records of varying durations. The records are available in the published reports of the U. S. Weather Bureau; and in unpublished records of the U. S. Forestry Service, the Los Angeles County Flood Control District, and other local agencies. Table Hyd. 4 is a tabulation of the number and duration of rainfall stations in the Los Angeles County Drainage Area and vicinity for which rainfall data are available."

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TABLE HYD. 2

NUMBER AND DURATION OF RAINFALL RECORDS

LOS ANGELES COUNTY DRAINAGE AREA AND VICINITY

<u>Number of Stations</u>	<u>Length of Record - Years</u>
3	Over 45
4	41 - 45
9	36 - 40
9	31 - 35
4	40 - 30
11	21 - 25
21	16 - 20
46	11 - 15
158	6 - 10
<u>179</u>	<u>1 - 5</u>
Total- 444	Mean Duration of all Records - 10 years

LOS ANGELES COUNTY DRAINAGE AREA AND VICINITY
NUMBER AND DURATION OF RAINFALL RECORDS
TABLE HYD. 2

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4	26 - 30
11	21 - 25
21	16 - 20
46	11 - 15
158	6 - 10
170	1 - 5
Total - 444	of all Records - 10 years
	Mean Duration

This listing does not include the groups operated by the San Dimas Experimental Forest, which area is within Los Angeles County. The extent of rainfall and runoff study at this experiment forest is indicated by the fact that the area consists of about 20 sq. miles of mountain territory and the number of gages in operation is about 239, of which 28 are automatic recording. Greatest concentration of gages is in Bell Canyon where approximately 48 gages cover only about .2 sq. miles.

Rainfall Distribution and Intensities on the Watershed

The variation of storm rainfall in the San Gabriel Watershed is mainly traceable to the distribution of the foot-hills and mountains in the area and to the relation of the watershed to prevailing storm winds.

The prevailing directions of the storm winds is from anywhere between the South and West. With the axis of the watershed Northeast to Southwest, and with the gently sloping plains area broken only by the low-lying Puente and San Jose foothills, both intensity of rainfall and total annual precipitation in this valley area increase gradually with increase of elevation, that is, from the coast to the foot of the San Gabriel Mountains. In the location of the Puente and San Jose Hills there is a slight increase above the general coast-to-foot-of-mountain rise in precipitation. However, from the foot of the mountains to the divide at the north border of the watershed, there is a very rapid increase in precipitation, with relatively heavy rainfall prevailing over the watersheds of the East and West forks of the San Gabriel River.

An isohyetal map ^{1/} showing 66 years (1872-1938) normal seasonal

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 Dumas Experimental Forest, which area is within Los Angeles County.
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 in Bell Canyon where approximately 18 gages cover only about 2.5 sq. miles.

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 An isohyetal map ¹ showing 66 years (1878-1943) normal seasonal

precipitations for Los Angeles County, prepared by the Los Angeles County Flood Control District, is shown in Map No. (). This indicates the normal seasonal precipitations at the coast, foot-hills, and base of mountains to be 11 inches, 18 inches, and 22 inches respectively. Over the forks of the San Gabriel Watershed, this precipitation approximates 30 to 35 inches, while on the high ridge forming the north border of the watershed, normal precipitations reach a maximum of 45 inches.

A comparison of the isohyetal maps of the March 1938 storm (Map #) with the isohyetal maps of the normal seasonal precipitations (Map #) shows considerable similarity in rainfall distribution over the watershed. ^{2/} The storm of March, 1938 was very general over the Los Angeles County Area, and this is probably true of storms of great magnitude. However, it is well known that storms of moderate magnitude over the Southern California area, any, and usually do, have local intensities that are very high and infrequent. The duration and character of the winds of these moderate storms probably determine the distribution and intensities of storm precipitation over the area, but little has been done toward an analysis of distribution of rain in these smaller storms.

1/ Make Photostat of L.A. CO. F.C.D. Map IV, titled "Isohyetal Map showing 66 year Normal (1872-1938) Seasonal Precipitations for Los Angeles County". Found on P. 24 of their Biennial Report on Hydrologic Data; storm of 1936-37 and 1937-38, dated June 30, 1939.

2/ Print the isohyetal map of 24-hour rainfall from "Hydrology" in Los Angeles County Drainage Area", March, 1939, Exhibit 35, U. S. Eng. Office, Los Angeles.

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1/ Make Photostat of L.A. Co. T.O.D. Map IV, titled "Isohyetal Map showing 66 Year Normal (1872-1937) Seasonal Precipitation for Los Angeles County". Found on P. 24 of their Biennial Report on Hydrologic Data; storm of 1926-27 and 1927-28, dated June 30, 1939.

2/ Print the isohyetal map of 24-hour rainfall from "Hydrology" in Los Angeles County Drainage Area", March, 1939, Exhibit 35, U. S. Eng. Office, Los Angeles.

An analysis of table Hyd. 1 shows that 59% of the total rainfall comes from the three less important types of storms and only 43% from the North Pacific type. What is more significant is that the total days of rain were equally divided between the North Pacific type and the three other types, indicating an average greater precipitation for the three erratic storm types.

An investigation of rainfall intensities of record in Los Angeles County indicates the importance of the moderate storm in local floods. Table Hyd. 3 gives the maximum of short-time intensities, up to 30 minutes, for 9 stations for the period of the record up to the March storm of 1938, and also the maximum intensities for the March storm for comparison. Record intensities in storms other than those of March 1938 storm average from 120 to 150 percent greater than maximum intensities recorded in the March storm. Table Hyd. 4 is a summary of the percent of record intensities attributed to storms of different magnitudes - (For definition of Magnitude, see Chapter__.) Note that for the five-minute intensities the percent of record intensities occurring in moderate storms is almost half of all the records made. The percent diminishes as the duration of intensity increases but it is still quite high at a 30-minute intensity. The average for moderate storms for this range of duration is higher than for any other class of storms.

In the U.S.D.A. flood control planning, which deals principally with the improvement of the watershed, it would seem that from a study of rain intensities and total rainfall the moderate storms may be of greater importance to flood control protection than the greater storms. This is particularly true when it is recognized that the more erratic

An analysis of Table Hyd. I shows that 55% of the total rainfall

comes from the three less important types of storms and only 45% from the North Pacific type. What is more significant is that the total days of rain were equally divided between the North Pacific type and the three other types, indicating an average greater precipitation for the three erratic storm types.

An investigation of rainfall intensities of record in Los Angeles

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attributed to storms of different magnitudes - (for definition of magnitude,

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record intensities occurring in moderate storms is almost half of all the

records made. The percent diminishes as the duration of intensity in-

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Table Hyd. 3
COMPARISON OF RECORD INTENSITIES TO
INTENSITIES OF STORM OF MARCH 2, 1938

From 9 Recording Stations in Los Angeles County ^{1/}

Location	Maximum 5-minute Intensities			Maximum 10-minute Intensities			Maximum 15-minute Intensities			Maximum 30-minute Intensities		
	Others than March 1938 Storm	March 1938(3)	March 1938 Storm	Others than March 1938 Storm	March 1938(3)	March 1938 Storm	Others than March 1938 Storm	March 1938(3)	March 1938 Storm	Others than March 1938 Storm	March 1938(3)	March 1938 Storm
	Date	Amount	Amt. In.	Date	Amt.	Amt. In.	Date	Amount	Amt. In.	Date	Amount	Amt. In.
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)
Opid's Camp	1926(1)	1.17	.38	1926(1)	1.18	.62	1926(1)	1.18	.82	1926(1)	1.52	1.20
Hoegge's Camp	1935	.41	.30	1935	.47	.43	1936	.58	.57	1936	.90	.83
Clear Creek	1938*	.35	.54	1938*	.42	.62	1930	.54	.67	1935	.82	.13
Camp Baldy	1938*	.21	.20	1938*	.30	.34	1938*	.39	.47	1938	.58	.92
Van Nuys	1931	.24	.13	1931	.31	.22	1931	.39	.32	1935	.55	.46
Sierra Madre	1935	.34	.25	1934(2)	.48	.30	1934(2)	.38	.36	1934(2)	.68	.58
Clearmont	1934(2)	.25	.18	1935	.30	.27	1934(2)	.36	.32	1934(2)	.58	.39
Hancock Park	1934(2)	.30	.30	1934(2)	.50	.36	1938	.62	.32	1937(2)	.96	.58
Los Angeles	1908(1)	.42	.18	1914(2)	.65	.29	1914(2)	.70	.38	1914(2)	1.14	1.14
Totals		<u>3.67</u>	<u>2.46</u>		<u>4.61</u>	<u>3.35</u>		<u>5.34</u>	<u>4.29</u>		<u>7.73</u>	<u>6.33</u>
Percent in term of March 1938 intensi- ties		150	100		140	100		120	100		120	100

^{1/} Data taken from L.A. CO. F.C.D. report by M. F. Burne, Flood of March 2, 1938, Table III.

* This was February 11, 1938 storm.

(1) Indicates magnitude, class I storm.

(2) Indicates magnitude, class II storm.

(3) March 1938 storm, class III storm.

Table Hyd. 4

PERCENT OF OCCURRENCE OF RECORD INTENSITIES IN
RELATION TO STORM MAGNITUDE

From 9 Recording Stations in Los Angeles County.

Magnitude	:	Percent occurring in magnitude				:	Total Percent
	:	of storms indicated <u>1/</u>				:	of each class
	:	5-min.	10-min.	15-min.	30-min.	:	
	:	int.	int.	int.	int.	:	
Class III *		11	22	22	11		17
Class II *		22	33	33	45		33
Class I *		22	11	11	11		14
Others		45	34	34	33		36

* For the description of Class magnitude See

1/ Data taken from Table Hydrology 1.

Table Hyd. 4

PERCENT OF OCCURRENCE OF RECORD INTENSITIES IN
RELATION TO STORM MAGNITUDE

From 2 Recording Stations in Los Angeles County.

Magnitude	Percent occurring in magnitude				Total Percent of each class
	5-min.	10-min.	15-min.	30-min.	
	int.	int.	int.	int.	
Class III *	11	22	22	11	17
Class II *	22	33	33	44	33
Class I *	22	11	11	11	14
Others	44	34	34	33	36

* For the description of Class magnitude see
V Data taken from Table Hydrology 1.

storms are of this moderate storm class and the greater proportion of these storms come early in the fall when watershed protection over the entire watershed is a minimum, or late in the spring when the agricultural portion of the watershed is poorly protected because of spring ploughing and planting.

Summing up the rainfall records for the Los Angeles Area, it can be said that though Southern California has the greatest concentration of rain gages in the U. S., the rough topography, the many characteristics of rain storms, and the dense population in and about so hazard an area, make the short period of effective rainfall records absolutely inadequate for a comprehensive prediction, of the probable rainfall, that is required for the close and complete organization of watershed protection.

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RUNOFF

Runoff Records:

Regarding Runoff records, the U.S.E.D. report already referred to stated:

"The oldest runoff records in the area are those of the U. S. Geological Survey. A stream-gaging station has been maintained near the mouth of San Gabriel Canyon since 1895. Data on the mountain flow of the main tributaries have been recorded since 1917. No records of runoff, other than occasional estimated peak flows, are available for valley stations prior to 1923. From 1923 to date, records at various places have been maintained by the California State Division of Water Resources ^{1/} and the Los Angeles County Flood Control District, supplemented by various local agencies".

A perspective of runoff records is given in the foreword of the report of the L.A. CO. F.C.D. of the runoff record section of the Biennial Report of the Hydrological Data, season of 1936-37 and 1937-38:

"Following the formation of the Flood Control District in Los Angeles County in 1915 with its resultant increase in flood control protective work, the lack of basic hydrologic records of sufficient length and scope became more apparent. In 1927, to satisfy this need for more basic design data, the Hydraulic Department was organized in order to establish and maintain permanent gaging stations on various streams and channels in the County. Some of these records continue uninterruptedly since 1927". ^{2/}

^{1/} Formerly known as the California State Department of Water.

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The number of recorder stations operating in Los Angeles County in 1938 was 71.

Under "Runoff Summary" in this same report the following statement is significant:

"The period (1936-37 and 1937-38) covered by this report produced the largest flood and had the greatest seasonal runoffs since records have been made available by the District. It is probable that the March 2, 1938 flood produced higher peak flows and greater volumes than either the floods of 1913-14 or 1915-16; and it is possible that the 1938 flood exceeded that of 1889-1890, for which no runoff records are available".

In other words, reliable runoff records are too short for the development of probability relationships.

Runoff Characteristics and Storm Magnitude:

Flow in the drainage channels of the San Gabriel River basin are representative of flow in drainage channels of the area within Los Angeles County south of the divide of the San Gabriel Mountains. In this area, typical of semi-arid climates, stream flow is intermittent and subject to wide variation. During the dry season stream beds are dry except for the drainage from irrigation water, or for the rise of the watertable over a subsurface dike close to the stream bed, and in some of the mountain canyon streams, for a few second-feet of flow that persists through the summer season, usually due largely to storage reservoirs.

In the winter season when most of the rain occurs, flow characteristics are flashy and flood peaks are of relatively short duration. For normal watershed conditions under high precipitation intensities time-of-concentration in the mountain streams is short, from a few minutes to probably considerably over 1 hour.

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Runoff Characteristics and Storm Manifestations

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But the average unit of watershed with which the U.S.D.A. deals, in both valley and mountain country, the time-of-concentration for these high intensities is probably less than one-half hour. In case of denuded watersheds, torrential flows debauch onto the foot hills and valley areas with probably much more rapid concentration time than for the normal watershed.

Runoff from both the mountains and valley areas is influenced by many factors. The most important of these factors are:

1. The relation of the slopes of the rugged terrain to the path of the storm; a sequence of intensities may be developed such that they are least or most effective in piling up the runoff.

2. Soil type; slope or drawings; dip of the formation beds with reference to topography, and their effect on infiltration, soil moisture storage and seepage. In a semi-arid climate such as in Southern California, due to both the absorptive and storage characteristics of the conditions named above, great amounts of rainfall may be absorbed, but when certain conditions have been satisfied, some of these characteristics may be reversed in function and actually increase the amount of rainfall that will run off.

Therefore the moisture condition of the soil, whether or not the antecedent rain of a flood intensity has decreased the intake of the soil to a minimum, or to what extent it has effected seepage, is important. In the very early fall, before the rainy season has begun, the soil moisture deficiency is very high so that an isolated heavy rain may be almost totally absorbed by the soil. The storm of September

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1939 was exceeded only twice in its maximum 24-hour intensity at Los Angeles and yet, because of the dry soil, runoffs from all except some small watersheds, was negligible. On the other hand, the heavy antecedent rain of the March 1938 storms, probably not only made infiltration a minimum but produced seepage of effective proportions at the time of the peak flow.

3. In the case of natural watershed vegetation, as in the mountain or foothill areas, runoff and erosion is increased by denudation from fire or, in grass land, by overgrazing. On agricultural lands, the time of season with respect to cropping operations on land use is most important. If in the early fall before vegetation has become effective, after the rainy season has begun and the soil moisture deficiency has been satisfied, runoff and erosion are relatively great; if after the winter vegetation has become effective, both runoff and erosion are reduced to a minimum; or if in the spring after ploughing or cultivation has exposed the bare, loose soil, runoff and erosion may be heavy.

4. The effect of the use of the land by man, whether he betters the infiltration rate and surface detention ability on the watershed by constant protection or encouragement of vegetation, or whether by misuse he decreases these factors, thereby decreasing or increasing the flood problem.

When the above conditions, which are liable to differ greatly from year to year, are combined with the erratic rainfall characteristics, existing meagre runoff data are of little value for the determination of peak runoff not to mention its greater inadequacy for the determination of probable runoff for all storm magnitude.

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Though very little data exists on peak discharge, and since the March 1938 storm was considered a great storm, it is of interest to compare past known peaks with that of the March flood peak. Table 5 gives the available data. The lack of adequate data for peak runoff from the medium sized watershed, together with the great variation in the rates of recorded runoff, and the complete lack of data for the small watersheds substantiates the contention that past records of runoff are of little use in projecting the probable picture of runoff for any appreciable years in the future.

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Table Hyd. 5

FROM RECORDS OF PEAK FLOW ESTIMATES
AT SELECTED POINTS IN THE
SAN GABRIEL RIVER WATERSHED 1/

Stream	Location	Drainage : area in : sq.mi.	Est. peak discharge : in sec.ft./ sq.mi. : 1938 : Other : Storm : Storms	Inches /hr : runoff for : maximum : value	
1	2	3	4	5	6
<u>Mountain Area</u>					
San Gabriel	Foothill Blvd Sta F 190 R	202.16	467	306 <u>2/</u>	.73 <u>4/</u>
W Fork San Gabriel	Sta P. 3R	102.00	333		.50
E " " "	" P. 4 R	81.40	438		.70
Bear Creek	Boy Sgt Camp	27.10	645		1.00
Big Dalton	Big Dalton Dam	4.49	290		.45
Little Dalton	Above Little Dalton Road	3.09	310	305 <u>2/</u>	.48-.47
San Dimas	San Dimas Dam	15.92	276	159 <u>2/</u>	.43
Live Oak	Live Oak Dam	2.30	154		.24
Rogers Creek	1500' above Sta U6R	6.12	352		2.10
<u>Foothill Area</u>					
San Jose Creek	Sta F 48 R	85.00	104	154 <u>3/</u>	2.28
" "	Collins Ave	15.30	59		.09
" "Trib	Nr Mill Dist Sch	.38	242		.38
" "	$\frac{1}{2}$ mi below Ha- ciendo Road	.37	843		1.32
Rodeo Canyon	- - - -	6.09	84		.13
Sycamore "	Trib S.G. below Workman Mill Rd	1.52	184		.29
Walnut Creek	Nr Walnut Ave	64.00	57	813 <u>3/</u>	.13
Coyote Creek	Sta F 41 CR	110.00	33	29 <u>3/</u>	.05
Turnbull Canyon	$1\frac{1}{2}$ Mi N Whittier Blvd	.95	379		.59

1/ From Burke, M. F. Flood of March 2, 1938, Table VI.

2/ From storm in 1914

3/ From New Years Storm of 1934

4/ Estimate or guess only

Table No. 2

FROM RECORDS OF PEAK FLOW ESTIMATES
AT SELECTED POINTS IN THE
SAN GABRIEL RIVER WATERSHED

Stream	Location	ad. mi.	1938	Other	maximum	Notes
			Storm	Storm	Value	
<u>Mountain Area</u>						
San Gabriel	Foot Hill Blvd					
	Sta 7 190 R	202.16				
W Fork San Gabriel	Sta P. 3R	102.00				
"	" P. 4 R	81.40				
Bear Creek	Box Set Camp	27.10				
Big Dalton	Big Dalton Dam	4.49				
Little Dalton	Above Little Dalton Road	3.09				
San Dimas	San Dimas Dam	15.92				
Live Oak	Live Oak Dam	2.30				
Rogers Creek	1500' above Sta UGR	6.12				
<u>Foot Hill Area</u>						
San Jose Creek	Sta 7 148 R	85.00				
"	Collins Ave	15.30				
"	Mr Will Dist Son	.38				
"	1/2 mi below Ha-					
Redo Canyon	elando Road	.71				
Spokane	Trlp S.G. below Workman Mill Rd	1.52				
Walnut Creek	Mr Walnut Ave	64.00				
Coyote Creek	Sta 7 41 GR	110.00				
Turnbull Canyon	1 1/2 mi N Whittier Blvd	.92				

From Burke, M. P. Flood of March 2, 1938, Table VI.
From storm in 1914
From New Years Storm of 1934
Estimate or guess only

Storm Frequency and Potential Storm Damages

Introduction

The term "frequency" is used here in its technical sense. It refers to the number of times on the average during any selected period that storms of a particular magnitude will be equaled or exceeded. Accordingly, in a period selected of 50 years, a storm equaled or exceeded twice, that is, with a frequency of 2.0, is termed a 25 year storm, or a 25 year frequency. It should be noted that the magnitude varies inversely with the frequency of occurrence, the less frequent storms and floods being of the greater magnitude, and vice versa.

As commonly used the term "frequency" indicates a rather generalized evaluation of the storm's magnitude over the watershed; but without the specific application to which the frequency is to be put, such an interpretation may be very misleading. This is so because a storm, like the March 1938 storm, may be a great storm for intensities of long duration such as would be necessary for the concentration of water at the lower reaches of the watershed, but a very moderate storm for short intensities such as are required for the concentration time for small headwater areas.

Since rain patterns over Southern California watersheds are more often erratic than consistent, we may assume that if on any watershed, only a part of the rain gages were read, very different storm frequencies might be derived than when all gages are read. Considering most watersheds as inadequately supplied with rain gages, it follows that any storm frequency estimate obtained from such a watershed is likely to be inaccurate or misleading in proportion to the erratic nature of the storm; therefore, storm magnitude may vary greatly with extent of completeness or incompleteness in gage covering of the watershed. Frequency data should, therefore,

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be supplemented or modified by information such as (1) the extent or comprehensiveness of the data and the area to which it applies, (2) whether the emphasis is on the short time high intensities such as affect the upper reaches of a watershed, or (3) whether on the longer sustained but moderate intensities that affect the lower reaches of the watershed, or (4) whether it is a combination of several or all of these factors and how they are combined or weighted.

Storm frequencies are usually developed for two general purposes, namely, (1) for determining how often a particular storm magnitude will be exceeded, that is, the storm frequency and (2) for determining the possible magnitude of storms yet to come. These general determinations in turn may be desired for one or more of the following purposes: (1) For the purpose of determining the greatest possible peak flow that can occur within a specified period of years for some specific point or stretch along a water course - this is, for the design of channels and weirs. (2) For the purpose of determining the greatest amount of water that may flow for an interval during which the flow is above a certain predetermined minimum - this is for the design of flood control reservoirs and for water storage. (3) For the determination of damages to be expected from storms likely to occur in the future.

The factors involved in the study of flood damages (item 3) include not only the items required under 1 and 2 but many others, such as quantity of flow at which damage begins in a certain natural channel; the magnitude and distribution of successive peak flows; the present and changing condition of land use and cover; the development of the works of man along the flood courses of the waterways, etc. The effect of change of cover and other constantly changing physical aspects of a watershed on the

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The factors involved in the study of flood damages (item 7) include

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of flow at which damage begins in a certain natural channel; the magnitude

and distribution of successive peak flows; the present and changing condi-

tion of land use and cover; the development of the works of man along the

flood courses of the waterways, etc. The effect of change of cover and

other constantly changing physical aspects of a watershed on the

magnitude of flood flows and consequently on flood damage is probably the most difficult factor to take into account.

It is entirely possible that by a study of the stream hydrographs and corresponding damages for flood flows in so-called representative watersheds, in both small and large areas, that a close relationship could be obtained between frequency and damage. This, no doubt, would be the most satisfactory way to approach the problem of estimating future flood damages, but the very nature of the material needed for relating run-off magnitude to storm magnitude would premise a very large task. Hydrograph and storm records necessary for such an undertaking would be extensive, and a thorough knowledge of both upstream and downstream watershed conditions would be necessary. However, the requisite storm and runoff data are not available and investigations to determine infiltration characteristics under different conditions of watershed cover and treatment are entirely lacking.

Future Damage Estimates Must be Based on Damages of the 1938 Storm.

The only general storm in the San Gabriel River watershed for which any reasonably adequate damage data are available is the storm of February 27 to March 2, 1938, referred to in this report as the "1938 storm." There was one storm in December 1938 which did appreciable damage but it was so scattered and of such relatively small over-all magnitude compared to the 1938 storm that with the very limited time available to the technicians of this survey at that time, little organized data were obtained. Erosion damage from this December storm in some places was very great, (see plate 15, photographs DG-1 and DG-2); however, the areas were very local because

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of the damage from this December storm in some places was very great, (see plate

15, photographs DG-1 and DG-2); however, the areas were very local because

of the large variation of intensity of the storm over the watershed.

The storm of September 1939, according to the 24 hour precipitation indicated, should be a storm of considerable magnitude; but run-off and damage from this storm was negligible. The lack of appreciable run-off from this storm was due to the fact that the soil moisture deficiency was at its maximum at the time. This condition coupled with the moderate intensities resulted in most of the rain going into the ground.

Owing to the fact that the usual yearly local storm damage is taken for granted, with the result that it is difficult to ascertain such damage from local observers, and to the unreliability of damage from storms occurring before the 1938 storm, it is necessary that the prediction of probable damage from future storms be based largely on the survey of damages from the 1938 storm.

In order to determine future flood damages in any particular part of the watershed, it was necessary to establish a method by which the damage produced by recent storms in any given flood source area could be related to the total damage to be expected in that area from all damage-producing storms which will probably occur in 50 years. Since the only adequate data of storm damage in the past 65 years of storm record is that of the 1938 storm, it might appear that any estimate of the total damage for all storms for the next 50 years would of necessity be somewhat questionable. However, it is believed that a reasonably reliable figure has been obtained by the combination of a simple rational analysis of the data for the 1938 storm superimposed upon an analysis of storm frequency developed from the most appropriate hydrologic data of storms of record, and with the entire tempered by the evaluation of historic storms and field observations.

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Frequency of the 1938 Storm

The only available data upon which to base the storm frequency analysis which must serve as the foundation for a storm damage study for the San Gabriel River watershed are records of (1) the one-hour maximum rainfall intensity, (2) the maximum day and maximum 24-hour rainfall and (3) the total storm rainfall. Total rainfall records are available for a great many years though the reliability of the earliest records is somewhat questionable. Maximum day rainfall and one hour maximum intensity records are available for a period of about 65 years at the Los Angeles Weather Bureau station. Automatic gages have been in use for the past 39 years and intensity records for various periods are also available at over 300 other rainfall stations in the county.

These three types of storm records are selected as the basis from which to determine storm frequencies from the standpoint of flood damage because:

- (1) The one-hour intensity is closely related to the peak flow.
- (2) The maximum day and maximum 24-hour rainfall are closely related to the maximum sustained inundating or highwater flow.
- (3) And the total storm rainfall is closely related to the total run-off and the tendency of long continued rains to saturate the soil, causing sloughing of stream banks, higher run-off and greater erosion.

An attempt was made to determine the relative importance of these three hydrologic factors with respect to the damage producing characteristics of a storm. The frequencies of these three hydrologic factors were ascertained for maximum yearly storms of record back to and including the storm of 1934 and combined by giving weights of various unequal ratios determined by what was thought to be the dominant factor in each storm with respect to its damage potentiality.

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These three types of storm records are selected as the basis from which to determine storm frequencies from the standpoint of flood damage because:

- (1) The one-hour intensity is closely related to the peak flow.
- (2) The maximum day and maximum 24-hour rainfall are closely related to the maximum sustained inundating or highwater flow.
- (3) And the total storm rainfall is closely related to the total runoff and the tendency of long continued rains to saturate the soil, causing sloughing of stream banks, higher runoff and greater erosion.

An attempt was made to determine the relative importance of these three hydrologic factors with respect to the damage producing character of a storm. The frequencies of these three hydrologic factors were ascertained for maximum yearly storms of record back to and including the storm of 1934 and combined by giving weights of various unequal ratios determined by what was thought to be the dominant factor in each storm with respect to its damage potentiality.

These studies have indicated that possibly the 24-hour precipitation is the most important of the three factors and that the short time intensities and the total rainfall factors should be made to only modify the 24-hour factor. However, because of the lack of corresponding damage data, the shifting nature of localized variation in storm intensity pattern, the variation in soil moisture condition before any storm, and the very short period of record over which data of any consequence are available, it was deemed impossible to determine a definite relationship of each of these factors to the others with respect to the damage potentiality of the storm they represent. In the light of this analysis it was decided that nothing more than a simple relationship of these factors should be attempted now. Therefore, the frequency curves were developed on the basis of equal weight to each factor. The procedure followed in the development of these curves was as follows:

Development of Chart No. H-1 (One-Hour Intensities)

The Los Angeles County Flood Control District has compiled rainfall data from the automatic recording stations and plotted these data into duration-intensity curves for various storm frequencies, such as 5, 10, 25, 50, and 100 years. Due to topography and the consequent variation in intensity patterns over the watershed for any one frequency, the hydrologists deemed it necessary to draw eight duration-intensity curves for each of the storm frequencies given. To apply these duration-intensity curves it was also necessary to make a map which showed the locations where each of the curves apply. This map was in the form of an isohyetal of storm intensity. The data for the one-hour intensity were developed from these curves and plotted

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Development of Chart No. H-1 (One-Hour Intensities)

The Los Angeles County Flood Control District has compiled rainfall data from the automatic recording stations and plotted these data into duration-intensity curves for various storm frequencies, such as 2, 10, 25, 50, and 100 years. Due to topography and the consequent variation in intensity patterns over the watershed for any one frequency, the hydrologists deemed it necessary to draw eight duration-intensity curves for each of the storm frequencies given. To apply these duration-intensity curves it was also necessary to make a map which showed the locations where each of the curves apply. This map was in the form of an isohyetal of storm intensity. The data for the one-hour intensities were developed from these curves and plotted

on chart No. H-1 (page ____). Since the boundaries of the five major sub-divisions of the watershed were selected for economic reasons, the subareas did not necessarily comprise more or less uniform storm characteristics. For this reason, it was necessary to divide the watershed into hydrologic areas or areas of reasonably uniform hydrological characteristics in order to develop storm frequency in sufficient detail. The watershed was divided into nine such areas and these areas are referred to on the curves of the charts where necessary. (See Fig. No. H-1).

It should be noted that the values used in chart No. H-1 had to be increased over the duration-intensity curves referred to above by a factor equal to .15. This increase was found necessary in order that the one-hour curves should conform with the U.S.E.D. data which form the basis for the 24-hour and total storm curves and which were of later origin.

The expected one-year intensity was determined by projecting the curves straight through from the five-year point which was the lowest period of time given by the data. This is consistent with the shape of all the curves.

Development of Chart No. H-2 (24-Hour Rainfall)

The Corps of Engineers, U. S. Army, at Los Angeles had computed the maximum day rainfall for various storm frequencies at the Los Angeles Weather Bureau station. This information was published in the report, "Hydrology in the Los Angeles County Drainage Area," and dated 1939.

The series of maximum 24-hour precipitation curves (chart H-2) were developed from the maximum day precipitation curves, because the available data were inadequate for direct plotting of the maximum 24-hour precipitation. The maximum day isohyetal map of the U.S.E.D. (exhibit 19, "Hydrology in the Los Angeles County Drainage Area") was used to find the maximum

on chart No. H-1 (page _____). Since the boundaries of the five major sub-divisions of the watershed were selected for economic reasons, the sub-divisions did not necessarily comprise more or less uniform storm characteristics. For this reason, it was necessary to divide the watershed into hydrologic areas or areas of reasonably uniform hydrological characteristics in order to develop storm frequency in sufficient detail. The watershed was divided into nine such areas and these areas are referred to on the curves of the charts where necessary. (See Plc. No. H-1).

It should be noted that the values used in chart No. H-1 had to be increased over the duration-intensity curves referred to above by a factor equal to 1.5. This increase was found necessary in order that the one-hour curves should conform with the U.S.E.D. data which form the basis for the 24-hour and total storm curves and which were of later origin.

The expected one-year intensity was determined by projecting the curves straight through from the five-year point which was the lowest period of time given by the data. This is consistent with the shape of all the curves.

Development of Chart No. H-2 (24-Hour Rainfall)

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The series of maximum 24-hour precipitation curves (chart H-2) were developed from the maximum day precipitation curves, because the available data were inadequate for direct plotting of the maximum 24-hour precipitation. The maximum day isohyets of the U.S.E.D. (Exhibit 19, "Hydrology in the Los Angeles County Drainage Area") was used to find the maximum

day rainfall to be expected once in 50 years in each of the hydrologic areas. Although this exhibit is entitled "24-hour Maximum Rainfall, Frequency of Occurrence Once in Fifty Years", it would appear to be actually "Maximum Day Rainfall." This was ascertained from a copy of the data from which the 50-year quantity for the Los Angeles station was determined.

This maximum day rainfall data were used to plot the rainfall-frequency curve, by the duration curve method, for Los Angeles and vicinity. It approximates a straight line on semi-logarithmic paper. This curve is indicated by dashed lines and marked "L.A.W.B. Max. Day," on Chart H-2. To get the curves for the other hydrologic areas, resort was made to the U.S.E.D. maximum day isohyetal map entitled "24-Hour Maximum Rainfall Frequency of Occurrence Once in 50 Years." This map was assumed to give the maximum day. By integrating the isohyets falling within each of the hydrologic areas the weighted average of maximum day precipitation for each of these areas was established. These quantities were used for the 50-year points for each of the curves representing the hydrologic areas.

Assuming that the curves for all the areas are of the same family, they will be straight on semi-logarithmic paper. It was deemed incorrect to assume that the lower points on these curves would have magnitudes proportional to the magnitude of the 50-year points from the zero base. It was concluded, therefore, that the difference in magnitude between any two 50-year points would be proportional to the differences in magnitude on the two curves at any greater frequency. To find these differences it was necessary to plot the duration curve for some other station of higher average precipitation rate than the Los Angeles station. Since a good record of 56 years exists at Glendora, this was used. The ratio of the difference in

day rainfall to be expected once in 50 years in each of the hydrologic areas. Although this exhibit is entitled "24-Hour Maximum Rainfall Frequency of Occurrence Once in Fifty Years", it would appear to be actually "Maximum Day Rainfall." This was ascertained from a copy of the data from which the 50-year quantity for the Los Angeles station was determined.

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magnitude of the L.A.W.B. curve and the Glendora curve between the 50-year and 1-year points was 0.268. This ratio was used throughout to determine the 1-year points of all the other curves. The eight curves for the eight hydrologic areas are represented in dashed lines in chart No. H-2 (page___).

Since these curves represent the maximum day, it was necessary to develop a method for deriving similar curves of maximum 24-hour precipitation because the maximum day record for a single storm, such as the 1938 storm, may vary greatly from the maximum 24-hour record. The latter was felt to be the only consistent relation to use for that particular frequency factor analysis. To accomplish this the record of maximum 24-hour rainfall for the damaging storms of record for the Los Angeles station were plotted as a duration series. (See chart H-4 and table H-2.) This gave the curve marked "L.A.W.B. Maximum 24-Hour" indicated in solid line on Chart No. H-2. This curve becomes tangent to the Maximum Day curve at about a 4-year frequency. Actually, it is believed that the curves ought to be slightly concave upward, but this refinement has too little effect upon the result to justify its further development. The total maximum 24-hour curve, therefore, was considered to be the solid-line which angles slightly at about the 4-year frequency. (Note that two points of this series of storms records coming between the 3- and 4-year period fell much below the rest of the point. This is due to the fact that the data plotted is for frequency of damaging storms and not for frequency of all storms above a certain base. If all storms were to be plotted these two storms would have fallen between a frequency of 1 to 2 years. Moisture condition of the soil as well as cover condition of the watershed at the time of one storm may produce a storm of damaging effect, whereas another storm of equal magnitude but under different soil moisture and cover conditions might produce no damage.) To get the other maximum 24-hour curves the following procedure was developed.

magnitude of the I.A.W.B. curve and the Glanders curve between the 50-year
 and 1-year points was 0.568. This ratio was used throughout to determine
 the 1-year points of all the other curves. The eight curves for the eight
 hydrologic areas are represented in dashed lines in chart No. H-2 (page ____).
 Since these curves represent the maximum day, it was necessary to de-
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 because the maximum day record for a single storm, such as the 1938 storm, may
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 To accomplish this the record of maximum 24-hour rainfall for the damaging
 storms of record for the Los Angeles station were plotted as a duration series.
 (See chart H-4 and table H-2.) This gave the curve marked "I.A.W.B. Maximum
 24-Hour" indicated in solid line on chart No. H-2. This curve becomes tangent
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 soil as well as cover condition of the watershed at the time of one storm may
 produce a storm of damaging effect, whereas another storm of equal magnitude
 but under different soil moisture and cover conditions might produce no damage.)
 To get the other maximum 24-hour curves the following procedure was developed.

It is noticed that on the L.A.W.B. curve at the 50-year frequency the ratio of maximum 24-hour rainfall to maximum day rainfall is $\frac{6.0}{4.9}$ or 1.22. By a study of the precipitation phenomena and mode of record taking, it was decided that this ratio decreased as the rainfall magnitude increased. The only comparisons for maximum 24-hour rainfall of record to that of 50-year maximum days rainfall for the same stations, which could be made in areas of high rainfall, were for the data at four mountain stations, that is, Opids, Hoegees, Clear Creek, and Camp Baldy. These data showed the 24-hour maximum rainfall to be about 1.1 of the average maximum day rainfall for the four stations. However, the maximum 24-hour rainfall of record at each of these stations is probably less frequent than 50 years. Therefore, the ratio of 50-year 24-hour to maximum day rainfall would be less than that found above. It was assumed to be 1.05 for the areas of high 24-hour 50-year rainfall. Between the extreme of Los Angeles and San Gabriel Mountains above Dam 2, intermediate values of the ratio of maximum 24-hour to maximum day at 50-year frequency were assumed as follows:

- 1.05 above San Gabriel Dam No. 2, San Dimas,
Big Dalton and Little Dalton Canyons.
- 1.10 above San Gabriel Dam No. 1, and the
San Gabriel Foothills.
- 1.15 San Jose and Walnut Creeks, Rodeo, La Brea,
and Carbon Canyons.
- 1.22 U.S.W.B., Foothills east and west of Fullerton,
Coastal Plains.

From these 50-year points for maximum 24 hour, straight lines were drawn to the 4-year frequency points on the corresponding maximum day curves. (Chart No. H-2.) As stated above the two curves seem to join at about this point. Between one and four year frequency the maximum day and the maximum 24-hour curves are assumed to coincide.

It is noticed that on the I.A.W.B. curve at the 50-year frequency the ratio of maximum 24-hour rainfall to maximum day rainfall is 0.9 or 1.2. By a study of the precipitation phenomena and mode of record taking, it was decided that this ratio decreased as the rainfall magnitude increased. The only comparisons for maximum 24-hour rainfall of record to that of 50-year maximum days rainfall for the same stations, which could be made in areas of high rainfall, were for the data at four mountain stations, that is, Golds, Hoogee, Clear Creek, and Camp Baldy. These data showed the 24-hour maximum rainfall to be about 1.1 of the average maximum day rainfall for the four stations. However, the maximum 24-hour rainfall of record at each of these stations is probably less frequent than 50 years. Therefore, the ratio of 50-year 24-hour to maximum day rainfall would be less than that found above. It was assumed to be 1.05 for the areas of high 24-hour 50-year rainfall. Between the extreme of Los Angeles and San Gabriel Mountains above Dam 5, intermediate values of the ratio of maximum 24-hour to maximum day at 50-year frequency were assumed as follows:

- 1.05 above San Gabriel Dam No. 2, San Dimas, Big Dalton and Little Dalton Canyons.
- 1.10 above San Gabriel Dam No. 1, and the San Gabriel foothills.
- 1.15 San Jose and Walnut Creeks, Hobbs, La Brea, and Carbon Canyons.
- 1.25 U.S.W.B., Foothills east and west of Teller, Coastal Plains.

From these 50-year points for maximum 24-hour, straight lines were drawn to the 4-year frequency points on the corresponding maximum day curves. (Chart No. H-2.) As stated above the two curves seem to join at about this point. Between one and four year frequency the maximum day and the maximum 24-hour curves are assumed to coincide.

Development of Chart No. H-3 (Total Storm Rainfall)

Data for plotting rainfall frequency curves for the San Gabriel watershed were obtained from L.A.W.B. records for damaging storms in the 55-year period from 1879 to 1938. The frequency of these storms was found by the Duration Curve method and the data for Los Angeles plotted as a rainfall-frequency curve, marked L.A.W.B. in chart No. H-3 (page). As in the maximum 24-hour curve, the lower points deviate from the expected direction of the curve. This is again attributed to the fact that a number of storms, of greater magnitude than those listed, are undoubtedly not included in this record since they might not have caused sufficient damage. If this is the case, in plotting a complete storm record the low points would be moved horizontally toward the 1-year frequency. This curve is also plotted as a straight line.

The curves for other hydrologic areas were plotted by relation to the Los Angeles curve, in the ratio of their mean seasonal rainfalls. Seasonal rainfall was determined from U.S.E.D. map of Exhibit 6, "Hydrology in the Rio Hondo and San Gabriel River Basins" (1938) entitled "Isohyetals for 64-year Normal Seasonal Precipitation". The values used in each area are shown in table H-1. A similar but more recent map is shown in Fig. ()*

Determination of Frequency of Storm Factors of 1938 Storm

The mean quantities for the three storm factors of the 1938 storm for each of the nine hydrological areas were obtained from the isohyets of the one-hour, twenty-four-hour, and total storm quantities for that storm in the same manner as the quantities were obtained for the maximum 24-hour rainfall, that is, by integrating the isohyets falling within

* See footnote 1/ page 12

Development of Chart No. H-3 (Total Storm Rainfall)

Data for plotting rainfall frequency curves for the San Gabriel watershed were obtained from L.A.W.R. records for damaging storms in the 58-year period from 1879 to 1938. The frequency of these storms was found by the Duration Curve method and the data for Los Angeles plotted as a rainfall-frequency curve, marked L.A.W.R. in chart No. H-3 (page). As in the maximum 24-hour curve, the lower points deviate from the expected direction of the curve. This is again attributed to the fact that a number of storms, of greater magnitude than those listed, are undoubtedly not included in this record since they might not have caused sufficient damage. If this is the case, in plotting a complete storm record the low points would be moved horizontally toward the 1-year frequency. This curve is also plotted as a straight line.

The curves for other hydrologic areas were plotted by relation to the Los Angeles curve, in the ratio of their mean seasonal rainfall. Seasonal rainfall was determined from U.S.E.D. map of Exhibit 6, "Hydrology in the Rio Hondo and San Gabriel River Basins" (1938) entitled "isohyets for 64-year Normal Seasonal Precipitation". The values used in each area are shown in table H-1. A similar but more recent map is shown in Fig. () *

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* See footnote 1, page 12

San Gabriel Rainfall-Frequency Data
According to Areas Covering Similar Hydrological Conditions

Average frequency of the 1938 storm for the upper watershed of the San Gabriel Valley	32.68
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each of the hydrological areas. These quantities were used to enter the appropriate curves of charts H-1, H-2, and H-3. (pages) and the corresponding frequencies obtained. These values are tabulated in table H-1, columns 3, 7 and 11. It is interesting to note the wide variation in frequency of the 1938 storm for the different storm factors and locations in the watershed.

It having been decided to give each of the three frequencies thus obtained for any one area equal weight in arriving at a combined frequency which would be an index of the damage producing frequency of the 1938 storm in that locality, the three frequencies were averaged arithmetically for each area and this figure is given in table H-1 under "Average local storm frequency". The weighted average for the 1938 storm for the watershed as a whole, developed on an area-frequency basis, was once in about every thirty-three years.

The average frequency is much higher than the popular conception of the frequency of the 1938 flood because, though it was a great storm for large areas, for the small watersheds the storm generally was not severe. Due to widespread newspaper publicity and great loss of life in the lower reaches of the larger streams, it has been popularly considered as a general storm of such magnitude as occurs only once in fifty or more years. This, as has already been pointed out, is true in the lower reaches of the Los Angeles, Tujunga and San Gabriel Rivers where the time of concentration is quite long, but on the smaller watersheds the peak flow was low. The storm, however, was quite general throughout the watershed.

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Damage From Any Storm as a Percent of the 50-year Storm Damage

Having found the frequency of the March 1938 storm and the damage in any area for this storm, it is necessary to develop the number and magnitude of storms that might be expected in the next 50 years in terms of the magnitude of the March 1938 storm, and then relate magnitude of storm to storm damage.

Since there are three factors involved in determining magnitude of a storm, a common unit of measure for magnitude must be used. As precipitation against time has been adopted as the magnitude of any hydrologic factor, it is only necessary to express this precipitation-time factor for any storm frequency in percent of the expected precipitation-time factor, for a 50-year frequency. In plotting these curves on semi-logarithmic paper, with frequency for the abscissae and percent of precipitation for the ordinates for each of the three hydrologic factors, all of the curves came out approximately straight. A composite of these curves will give a single curve with the ordinate at any frequency expressed as a percent of the composite magnitude of the three factors taken at a 50 year frequency. Such a composite curve for the three factors is given in curve (A) of chart H-5. Note here that the quantity of precipitation for the three hydrologic factors for a 2-year storm is 50% of that of a 50 year storm.

It is necessary now to develop correlation between storm damage and storm magnitude. To determine a rational and accurate relationship for this correlation, it should be necessary to make a comprehensive damage survey after every damaging storm in a 50 year period and correlate the damage with the known frequency of the particular storm. Records

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It is necessary now to develop correlation between storm damage and storm magnitude. To determine a rational and accurate relationship for this correlation, it should be necessary to make a comprehensive damage survey after every damaging storm in a 50 year period and correlate the damage with the known frequency of the particular storm. Records

of past storms here are inadequate so an appraisal of historic storms is the only possible substitute. The most comprehensive material discovered was a tabulation and classification of past flood years that has been developed by the Corps of Engineers, U. S. Army. It is a chart that shows the magnitude of the floods of past years as far back as 1810 classified into three groups of storms by judgment based on historical records such as newspaper accounts, private records, etc. (see chart H-4 on page). The three classifications are as follows:

- Class 1 - high rainfall intensity for 10 to 60 minutes.
Damage confined to small areas.
- Class 2 - high rainfall intensity for 1 to 2 hours, following 3 or 4-day storms. Damage along river channels and loss of life.
- Class 3 - rain for 2 to 4 weeks followed by rain of high intensity for 2 to 4 hours. Loss of life and great damage to property.

The U. S. Weather Bureau has been able to furnish the data on the amount of rain which fell during the maximum 24-hour period and for each entire storm at the Los Angeles station for as far back as the 1879-80 season. The Corps of Engineers' classification of storms, together with the Weather Bureau rainfall data are shown in table No. H-2.

Curve E in Chart H-5 is a composite of two estimates of flood damages from historical storms, reduced to a 50 year period, taken from the "Los Angeles and San Gabriel rivers and their tributaries - Flood Control Report of April 23, 1938, U.S.E.D."; and "Los Angeles and San Gabriel Rivers and their tributaries, and Ballona Creek, Flood Control Report of March 15, 1939, U.S.E.D."

The first mentioned of these two records, seemed to be the most comprehensive attempt to appraise past storm damage. When individual

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The three classifications are as follows:

- Class 1 - high rainfall intensity for 10 to 60 minutes. Damage confined to small areas.
- Class 2 - high rainfall intensity for 1 to 2 hours, following 1 or 2-day storms. Damage along river channels and loss of life.
- Class 3 - rain for 2 to 4 weeks followed by rain of high intensity for 2 to 4 hours. Loss of life and great damage to property.

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Table No. H-2.
Historical and Recorded Floods of the
Los Angeles Watershed, Grouped in Three
Orders of Magnitudes, 1810-1938. 1/

	Class of Flood			Rainfall at Los Angeles		
	Magnitude					Months
Flood				Maximum	Total storm	and
year	No. 1	No. 2	No. 3	24-hour	rainfall	days of
	Small	Medium	Large	in inches	in inches	rainfall
1	2	3	4	5	6	7
1810-11	1			2/	2/	
1814-15	1					
1921-22		2				
1825-26			3			
1833-34		2				
1839-40			3			
1841-42		2				
1849-50		2				
1852-53		2				
1859-60	1					
1861-62			3			
1867-68		2				
1873-74	1					
1875-76	1					
1879-80	1			4.34	4.71	12/19 - 23
1883-84			3	3.63 2/	7.12	2/14 - 18
1885-86		2		3.77	6.51	1/16 - 21
1889-90			3	4.30	6.26	12/18 - 26
1892-93	1			3.75	5.96	11/26 - 12/3
1900-01	1			3.70	6.53	11/16 - 22
1902-03	1			3.35	3.37	3/24 - 25
1904-05	1			2.41	4.43	3/11 - 16
1908-09	1			3.17	5.93	1/20 - 27
1910-11	1			2.97	4.89	1/24 - 31
1913-14		2		4.26	7.04	2/18 - 21
1915-16		2		4.20	6.90	1/14 - 19
1921-22	1			2.37	7.90	12/17 - 23
1925-26	1			3.14	7.34	4/3 - 8
1926-27	1			3.35	6.40	2/10 - 16
1933-34		2		7.36	8.27	12/29 - 1/2
1937-38			3	6.28	11.06	2/27 - 3/4
Total						
129 years	15	10	6			
Frequency						
in years	4.2	8.1	21.5			

Total number of storms occurred: 31

- 1/ Historical data on flood magnitude in part from U.S. Engineer Office, supplemented by information taken from report by H.B. Lynch on "Rainfall and Stream Runoff in Southern California since 1769."
- 2/ Data not available from 1810 to 1879.
- 3/ Maximum day's rainfall. Data from report of M.F. Burke on "Flood of March 2, 1938", for the Los Angeles County Flood Control District, table VI.

Table No. H-5.

Historical and Recorded Floods of the
Los Angeles Watershed, Grouped in Three
Orders of Magnitudes, 1810-1978.

Year	Order of Magnitude	Class of Flood	Estimated at Los Angeles	Months and days of rainfall
1977-78	3	1	11.06	2/27 - 3/4
1977-78	3	2	6.58	1/25 - 1/28
1977-78	3	3	1.36	12/29 - 1/2
1977-78	3	4	8.27	2/10 - 2/12
1977-78	3	5	6.10	2/10 - 2/12
1977-78	3	6	7.34	2/10 - 2/12
1977-78	3	7	7.37	2/10 - 2/12
1977-78	3	8	7.90	2/10 - 2/12
1977-78	3	9	6.90	2/10 - 2/12
1977-78	3	10	7.04	2/10 - 2/12
1977-78	3	11	8.89	2/10 - 2/12
1977-78	3	12	5.97	2/10 - 2/12
1977-78	3	13	5.17	2/10 - 2/12
1977-78	3	14	5.01	2/10 - 2/12
1977-78	3	15	3.35	2/10 - 2/12
1977-78	3	16	3.70	2/10 - 2/12
1977-78	3	17	3.75	2/10 - 2/12
1977-78	3	18	4.30	2/10 - 2/12
1977-78	3	19	5.77	2/10 - 2/12
1977-78	3	20	6.51	2/10 - 2/12
1977-78	3	21	7.15	2/10 - 2/12
1977-78	3	22	4.71	2/10 - 2/12
1977-78	3	23	12.19	2/10 - 2/12
1977-78	3	24	12.19	2/10 - 2/12
1977-78	3	25	12.19	2/10 - 2/12
1977-78	3	26	12.19	2/10 - 2/12
1977-78	3	27	12.19	2/10 - 2/12
1977-78	3	28	12.19	2/10 - 2/12
1977-78	3	29	12.19	2/10 - 2/12
1977-78	3	30	12.19	2/10 - 2/12
1977-78	3	31	12.19	2/10 - 2/12
1977-78	3	32	12.19	2/10 - 2/12
1977-78	3	33	12.19	2/10 - 2/12
1977-78	3	34	12.19	2/10 - 2/12
1977-78	3	35	12.19	2/10 - 2/12
1977-78	3	36	12.19	2/10 - 2/12
1977-78	3	37	12.19	2/10 - 2/12
1977-78	3	38	12.19	2/10 - 2/12
1977-78	3	39	12.19	2/10 - 2/12
1977-78	3	40	12.19	2/10 - 2/12
1977-78	3	41	12.19	2/10 - 2/12
1977-78	3	42	12.19	2/10 - 2/12
1977-78	3	43	12.19	2/10 - 2/12
1977-78	3	44	12.19	2/10 - 2/12
1977-78	3	45	12.19	2/10 - 2/12
1977-78	3	46	12.19	2/10 - 2/12
1977-78	3	47	12.19	2/10 - 2/12
1977-78	3	48	12.19	2/10 - 2/12
1977-78	3	49	12.19	2/10 - 2/12
1977-78	3	50	12.19	2/10 - 2/12
1977-78	3	51	12.19	2/10 - 2/12
1977-78	3	52	12.19	2/10 - 2/12
1977-78	3	53	12.19	2/10 - 2/12
1977-78	3	54	12.19	2/10 - 2/12
1977-78	3	55	12.19	2/10 - 2/12
1977-78	3	56	12.19	2/10 - 2/12
1977-78	3	57	12.19	2/10 - 2/12
1977-78	3	58	12.19	2/10 - 2/12
1977-78	3	59	12.19	2/10 - 2/12
1977-78	3	60	12.19	2/10 - 2/12
1977-78	3	61	12.19	2/10 - 2/12
1977-78	3	62	12.19	2/10 - 2/12
1977-78	3	63	12.19	2/10 - 2/12
1977-78	3	64	12.19	2/10 - 2/12
1977-78	3	65	12.19	2/10 - 2/12
1977-78	3	66	12.19	2/10 - 2/12
1977-78	3	67	12.19	2/10 - 2/12
1977-78	3	68	12.19	2/10 - 2/12
1977-78	3	69	12.19	2/10 - 2/12
1977-78	3	70	12.19	2/10 - 2/12
1977-78	3	71	12.19	2/10 - 2/12
1977-78	3	72	12.19	2/10 - 2/12
1977-78	3	73	12.19	2/10 - 2/12
1977-78	3	74	12.19	2/10 - 2/12
1977-78	3	75	12.19	2/10 - 2/12
1977-78	3	76	12.19	2/10 - 2/12
1977-78	3	77	12.19	2/10 - 2/12
1977-78	3	78	12.19	2/10 - 2/12
1977-78	3	79	12.19	2/10 - 2/12
1977-78	3	80	12.19	2/10 - 2/12
1977-78	3	81	12.19	2/10 - 2/12
1977-78	3	82	12.19	2/10 - 2/12
1977-78	3	83	12.19	2/10 - 2/12
1977-78	3	84	12.19	2/10 - 2/12
1977-78	3	85	12.19	2/10 - 2/12
1977-78	3	86	12.19	2/10 - 2/12
1977-78	3	87	12.19	2/10 - 2/12
1977-78	3	88	12.19	2/10 - 2/12
1977-78	3	89	12.19	2/10 - 2/12
1977-78	3	90	12.19	2/10 - 2/12
1977-78	3	91	12.19	2/10 - 2/12
1977-78	3	92	12.19	2/10 - 2/12
1977-78	3	93	12.19	2/10 - 2/12
1977-78	3	94	12.19	2/10 - 2/12
1977-78	3	95	12.19	2/10 - 2/12
1977-78	3	96	12.19	2/10 - 2/12
1977-78	3	97	12.19	2/10 - 2/12
1977-78	3	98	12.19	2/10 - 2/12
1977-78	3	99	12.19	2/10 - 2/12
1977-78	3	100	12.19	2/10 - 2/12

Total

129 years

Frequency

in years

U.S. 8.1 21.5

Total number of storms occurred: 51

1/ Historical data on flood magnitude in part from U.S. Engineer Office, supplemented by information taken from report by H.H. Lynch on "Rainfall and Stream Runoff in Southern California since 1769".

2/ Data not available from 1810 to 1870.

3/ Maximum day's rainfall. Data from report of H.H. Lynch on "Flood of March 2, 1978", for the Los Angeles County Flood Control District, Table VI.

storms and their damage were plotted the curve came about half way between curve E and curve B-C; however, in the schedule of storms the damage for ten class-1 storms in 100 years, as listed in chart H-4 and table H-2, had not been appraised. From the fact of the great variation in the damage data developed, as well as the acknowledged conjectural character of the material, an attempt to apply this data to the headwater areas of the San Gabriel watershed would seem entirely inadequate and inappropriate. It is felt that for the type of watersheds surveyed by the U.S.D.A., that the most practicable correlation of storm damage to magnitude is accomplished most satisfactorily by determining bottom and top limits and then developing a curve between these limits that seem to satisfy the greatest number of observed facts. To this end the curve B-C of chart H-5 was developed on the following assumptions:

- 1) The upper limit of storm magnitude will be a 50 year storm
- 2) The lower limit will be a two year storm
- 3) Between these limits the storm damage curve will be of the same shape as the storm magnitude curves.

The reasons for these assumptions are as follows: (1) Fifty years has been the economic period over which the work is to be carried. Though the probability admits that in this period of time one storm may be equal to or greater than 50 years, two equal to or greater than a 25-year storm; and that the greater storm may be of any frequency, even a 1000 year more or less, and the others may be greater than the minimum as expressed by the frequency; nevertheless, the accuracy with which all the factors involved may be worked out does not justify improvement beyond assuming an ideal alignment of values.

- (2) The lower limit is the magnitude of storm from which appreciable

storms and their damage were plotted the curve came about half way between curve K and curve H-C; however, in the schedule of storms the damage for ten class-I storms in 100 years, as listed in chart H-4 and table H-2, had not been appraised. From the fact of the great variation in the damage data developed, as well as the acknowledged conjectural character of the material, an attempt to apply this data to the headwater areas of the San Gabriel watershed would seem entirely inadequate and inappropriate. It is felt that for the type of watersheds surveyed by the U.S.D.A., that the most practicable correlation of storm damage to magnitude is accomplished most satisfactorily by determining bottom and top limits and then developing a curve between these limits that seem to satisfy the greatest number of observed facts. To this end the curve H-C of chart H-2 was

developed on the following assumptions:

- 1) The upper limit of storm magnitude will be a 50 year storm
- 2) The lower limit will be a two year storm
- 3) Between these limits the storm damage curve will be of the same shape as the storm magnitude curves.

The reasons for these assumptions are as follows: (1) Fifty years has been

the economic period over which the work is to be carried. Though the probability admits that in this period of time one storm may be equal to or greater than 50 years, two equal to or greater than a 25-year storm; and that the greater storm may be of any frequency, even a 1000 year

more or less, and the others may be greater than the minimum as expressed by the frequency; nevertheless, the accuracy with which all the factors involved may be worked out does not justify improvement beyond assuming an ideal alignment of values.

- (2) The lower limit is the magnitude of storm from which appreciable

damage can be expected. Field observations and damage surveys show that much damage is done every year in localized areas where intensities appear to be greater than the average yearly intensity. (See photographs on erosion and deposition). Also, because channels in the cones and upper watershed areas are usually poorly defined, the lower limit of storm magnitude that will cause damage is much lower than should be expected in the lower reaches of the watershed. (3) The damage curve must closely follow the storm magnitude curve for three important reasons: first, because the combination of the three hydrologic factors tends to bring storm magnitude parallel to damage; second, general storm damage begins at a two-year storm when the average quantitative expression of the storm in terms of the three hydrologic factors is 50% of the fifty-year storm, that is, it begins at a high rate; and third, because since the March 1938 storm had a frequency of only 33 years and since the damage for the projected 50 year period is to be largely estimated from the 1938 storm, any discrepancy in damage ratio to magnitude below the 33 year point on the curve will be largely compensated by a discrepancy above the point which will be in the opposite direction.

At the time of development of the Los Angeles report, it was felt that for the smaller watersheds the U.S.E.D. classification of storms did not include all damaging storms, ^{1/} so one more class 1 magnitude storm was added which was to have compensated for all the storms of less magnitude than the lowest class which caused damage. Since this report, additional observation on the season to date has shown that storms with frequencies

^{1/} U.S.D.A. Field Flood Control Coordinating Committee No. 18, Survey Report for the L. A. River, Appendices, See B, page 15.

damage can be expected. Field observations and damage surveys show that much damage is done every year in localized areas where intensities appear to be greater than the average yearly intensity. (See photographs on erosion and deposition). Also, because channels in the cones and upper watershed areas are usually poorly defined, the lower limit of storm magnitude that will cause damage is much lower than should be expected in the lower reaches of the watershed. (3) The damage curve must closely follow the storm magnitude curve for three important reasons: first, because the combination of the three hydrologic factors tends to bring storm magnitude parallel to damage; second, general storm damage begins at a two-year storm when the average quantitative expression of the storm in terms of the three hydrologic factors is 50% of the fifty-year storm, that is, it begins at a high rate; and third, because since the March 1938 storm had a frequency of only 33 years and since the damage for the projected 70 year period is to be largely estimated from the 1938 storm, any discrepancy in damage ratio to magnitude below the 33 year point on the curve will be largely compensated by a discrepancy above the point which will be in the opposite direction.

At the time of development of the Los Angeles report, it was felt that for the smaller watersheds the U.S.E.D. classification of storms did not include all damaging storms, so one more class I magnitude storm was added which was to have compensated for all the storms of less magnitude than the lowest class which caused damage. Since this report, additional observation on the reason to date has shown that storms with frequencies

U.S.D.A. Field Flood Control Coordinating Committee No. 12, Survey Report for the L. A. River, Appendix, See B, page 12.

as low as two years do appreciable general damage, and that damage, on isolated area, from erosion, washing, and siltation is appreciable every year. (See plate _____). This would bring the total damaging storms for a 50-year period to practically twenty-five, and this is the number of storm used to develop curve B-C of chart H-5.

Chart No. H-5 gives the ratio of damages to be expected from a storm of any known frequency, expressed as a percentage of the damages resulting from a fifty-year storm as an unknown quantity but established as at 100%. The answer desired is an expression of the total damages expected from all storms during a fifty-year period in terms of the damage from known storms; in this case it is only one storm, the 1938 storm.

The plotting of the twenty-five storms as curve "B-C" of chart No. H-5 was by the average interval between floods or the "California" method. 2/ That is, there have been determined to be two storms during a fifty-year period which equal or exceed the twenty-five year storm, and they are plotted at twenty-five and fifty-year frequencies. The same analysis can be applied to the other storms plotted. For example, there must be five storms which equal or exceed the ten-year storm in a fifty-year period according to the accepted definition of storm frequency, and an average distribution of these storms on the curve will be 50, 25, 16.7, 12.5, 10-year, etc. storm frequencies.

The reason for using this method of plotting is that in the duration method used, a storm is plotted at the mid-point of the division of the percent of time axis that represents that storm, but in the damage curve the storms are storms that are assumed to have occurred and their

as low as two years to appreciable general damage, and that damage, on is
lated area, from erosion, washing, and alluvion is appreciable every year
(see plate _____). This would bring the total damaging storms for a
50-year period to practically twenty-five, and this is the number of storms
needed to develop curve B-C of chart H-5.

Chart No. H-5 gives the ratio of damages to be expected from a
storm of any known frequency, expressed as a percentage of the damages
resulting from a fifty-year storm as an unknown quantity but established
as at 100%. The answer desired is an expression of the total damages
expected from all storms during a fifty-year period in terms of the damage
from known storms; in this case it is only one storm, the 1938 storm.

The plotting of the twenty-five storms as curve "B-C" of chart
No. H-5 was by the average interval between floods or the "California"
method. That is, there have been determined to be two storms during
a fifty-year period which equal or exceed the twenty-five year storm,
and they are plotted at twenty-five and fifty-year frequencies. The
same analysis can be applied to the other storms plotted. For example,
there must be five storms which equal or exceed the ten-year storm in
a fifty-year period according to the accepted definition of storm fre-
quency, and an average distribution of these storms on the curve will be
50, 25, 16.7, 12.5, 10-year, etc. storm frequencies.

The reason for using this method of plotting is that in the
duration method used a storm is plotted at the mid-point of the division
of the percent of time axis that represents that storm, but in the damage
curve the storms are storms that are assumed to have occurred and their

magnitudes are the actual magnitudes given. The number of storms and the period of record from which their frequencies have been derived, of course, may vary greatly with the data available.

The sum of all ordinates for the twenty-five storms was computed and came out to be 696% or, in other words, all damages over a 50-year period from all storms would be 6.96 times the damage to be expected from the maximum 50-year storm. To use this curve it is only necessary to know the frequency of one storm and the damage it incurred. With its frequency established, the value of its ordinate on the curve may be determined. By dividing this value into the 696%, there is obtained the 50-year storm damage factor in terms of the damage for that particular storm. By multiplying the money value of damages from this storm by the 50-year storm-damage factor the estimated damages from all storms for the area for the next fifty years will be determined in money.

In table No. H-3 are tabulated the three individual storm factors, the average local storm frequency (column 6), and in the last column the factors for the subareas considered by which the damages from the 1938 flood must be multiplied in order to obtain the total assumed 50-year damage for that area. These values have been used to obtain the total flood damage for the fifty-year period over which the flood control estimates have been calculated. Note that the first six columns are a reorganization of table No. H-1 according to subareas instead of hydrological areas. Column 7 was obtained by applying the factors in column 6 to curve "B-C" of chart No. H-5.

It is of interest to note that the magnitude of Class 1, 2 and 3 storms as developed in the U.S.D.A. Flood Control Report for the Los

storms as developed in the U.S.D.A. Flood Control Report for the Los

It is of interest to note that the magnitude of Class I, 2 and 3

to curve "B-C" of chart No. H-5.

cal areas. Column 7 was obtained by applying the factors in column 6

reorganization of table No. H-1 according to subareas instead of hydrologi-
estimates have been calculated. Note that the first six columns are a

total flood damage for the fifty-year period over which the flood control

50-year damage for that area. These values have been used to obtain the

the 1938 flood must be multiplied in order to obtain the total assumed

factors for the subareas considered by which the damages from

the average local storm frequency (column 6), and in the last column the

In table No. H-7 are tabulated the three individual storm factors,

next fifty years will be determined in money.

damage factor the estimated damages from all storms for the area for the

multiplying the money value of damages from this storm by the 50-year storm-

storm damage factor in terms of the damage for that particular storm. By

mined. By dividing this value into the 50%, there is obtained the 50-year

frequency established, the value of its ordinate on the curve may be deter-

know the frequency of one storm and the damage it incurred. With its

from the maximum 50-year storm. To use this curve it is only necessary to

period from all storms would be 6.96 times the damage to be expected

and came out to be 696% or, in other words, all damages over a 50-year

The sum of all ordinates for the twenty-five storms was computed

may vary greatly with the data available.

period of record from which their frequencies have been derived, of course,

magnitudes are the actual magnitudes given. The number of storms and the

Table No. H-3.

The Frequency of the 1938 Storm for Subareas
of the San Gabriel Watershed and the Ratio of Damage
Potentials of 50 years of Future Storms
to that of the 1938 Storm.

Flood source : Area in : Frequency of March 2, 1938 Storm : Ratio of total						
areas and sub- : sq.mi. : Based on: Based on: Based on: Based on the: 50-year damage						
areas : : total : 24-hour : max. 1-hr: 3 weighted : to 1938 storm						
: : rainfall: rainfall: rainfall: factors : damage						
(1)	(2)	(3)	(4)	(5)	(6)	(7)
Area No. 1						
Subarea "A"	40.42	54	22	3	26	8.76
Subarea "B"	161.58	75	29	3	36	7.76
Subarea "C"	8.80	98	15	1	38	7.61
Subarea "D"-1	15.11	98	15	1	38	7.61
Subarea "D"-2	10.15	70	13	1	28	8.49
Area No. 2						
Subarea "A"	3.30	98	15	1	38	7.61
Subarea "B"	8.41	70	13	1	28	8.49
Subarea "C"	4.49	98	15	1	38	7.61
Subarea "D"	2.73	70	13	1	28	8.49
Subarea "E"	9.25	70	13	1	28	8.49
Subarea "F"	15.92	98	15	1	38	7.61
Subarea "G"	2.57	70	13	1	28	8.49
Subarea "H"	7.81	46	7	1	18	10.24
Subarea "I"	2.30	70	13	1	28	8.49
Subarea "J"	12.34	70	13	1	28	8.49
Subarea "K"	26.23	46	7	1	18	10.24
Subarea "L"	6.18	46	7	1	18	10.24
Subarea "M"	2.18	46	7	1	18	10.24
Subarea "N"	12.36	46	7	1	18	10.24
Area No. 3						
Subarea "A"	3.91	70	13	1	28	8.49
Subarea "B"	80.23	46	7	1	18	10.24
Area No. 4						
Subarea "A"	23.40	54	7	1	21	9.53
Subarea "B"	17.90	39	8	1	16	10.79
Subarea "C"	2.05	150	14	1	55	6.76
Subarea "D"	3.05	150	14	1	55	6.76
Subarea "E"-1	37.00	150	14	1	55	6.76
Subarea "F"-2	98.84	100	18	1	40	7.48
Area No. 5						
Entire area	84.70	100	18	1	40	7.48
Total area	703.21	Average for watershed:			32.68	8.05

Total Damage % = 696%

Total Damage \$ = 666

storm as developed in the report for the last

Total area 703.21 Average for watershed 32.68

Native area 84.70 100 18 1 40 1.48

Area No. 5

Subarea "A" 98.84 100 18 1 40 1.48

Subarea "B" 27.00 150 14 1 25 6.76

Subarea "C" 37.05 150 14 1 25 6.76

Subarea "D" 2.05 150 14 1 25 6.76

Subarea "E" 17.90 30 8 1 16 10.24

Subarea "F" 23.40 24 7 1 12 9.27

Area No. 4

Subarea "A" 80.23 46 7 1 18 10.24

Subarea "B" 3.91 70 13 1 28 8.49

Area No. 3

Subarea "A" 12.36 46 7 1 18 10.24

Subarea "B" 2.18 46 7 1 18 10.24

Subarea "C" 6.18 46 7 1 18 10.24

Subarea "D" 26.23 46 7 1 18 10.24

Subarea "E" 12.34 70 13 1 28 8.49

Subarea "F" 2.30 70 13 1 28 8.49

Subarea "G" 7.81 46 7 1 18 10.24

Subarea "H" 2.57 70 13 1 28 8.49

Subarea "I" 15.92 98 15 1 38 7.61

Subarea "J" 9.27 70 13 1 28 8.49

Subarea "K" 2.73 70 13 1 28 8.49

Subarea "L" 4.49 98 15 1 38 7.61

Subarea "M" 8.41 70 13 1 28 8.49

Subarea "N" 3.30 98 15 1 38 7.61

Area No. 2

Subarea "A" 10.15 70 13 1 28 8.49

Subarea "B" 15.11 98 15 1 38 7.61

Subarea "C" 8.80 98 15 1 38 7.61

Subarea "D" 161.28 75 15 1 38 7.61

Subarea "E" 40.42 24 7 1 18 10.24

Area No. 1

Subarea "A" 22 24 7 1 18 10.24

Subarea "B" 29 24 7 1 18 10.24

Subarea "C" 15 15 1 1 18 10.24

Subarea "D" 15 15 1 1 18 10.24

Subarea "E" 28 28 1 1 38 7.61

Subarea "F" 36 36 1 1 38 7.61

Subarea "G" 36 36 1 1 38 7.61

Subarea "H" 36 36 1 1 38 7.61

Subarea "I" 36 36 1 1 38 7.61

Subarea "J" 36 36 1 1 38 7.61

Subarea "K" 36 36 1 1 38 7.61

Subarea "L" 36 36 1 1 38 7.61

Subarea "M" 36 36 1 1 38 7.61

Subarea "N" 36 36 1 1 38 7.61

The frequency of the 1938 storm for Subareas of the San Gabriel watershed and the ratio of damage
Potential of 50 years of future storms
to that of the 1938 storm.

Area in : Frequency of March 2, 1938 storm : Ratio of total
area and exp.: sq. mi. : Based on: Based on the 50-year damage
area : total : 24-hour max. 1-hr : 5 weighted : to 1938 storm
: rainfall: rainfall: factors : damage

(1)	(2)	(3)	(4)	(5)	(6)	(7)
Area No. 1						
Subarea "A"	40.42	24	22	3	28	8.49
Subarea "B"	161.28	75	29	3	36	7.61
Subarea "C"	8.80	98	15	1	38	7.61
Subarea "D"-1	15.11	98	15	1	38	7.61
Subarea "D"-2	10.15	70	13	1	28	8.49
Area No. 2						
Subarea "A"	3.30	98	15	1	38	7.61
Subarea "B"	8.41	70	13	1	28	8.49
Subarea "C"	4.49	98	15	1	38	7.61
Subarea "D"	2.73	70	13	1	28	8.49
Subarea "E"	9.27	70	13	1	28	8.49
Subarea "F"	15.92	98	15	1	38	7.61
Subarea "G"	2.57	70	13	1	28	8.49
Subarea "H"	7.81	46	7	1	18	10.24
Subarea "I"	2.30	70	13	1	28	8.49
Subarea "J"	12.34	70	13	1	28	8.49
Subarea "K"	26.23	46	7	1	18	10.24
Subarea "L"	6.18	46	7	1	18	10.24
Subarea "M"	2.18	46	7	1	18	10.24
Subarea "N"	12.36	46	7	1	18	10.24
Area No. 3						
Subarea "A"	3.91	70	13	1	28	8.49
Subarea "B"	80.23	46	7	1	18	10.24
Area No. 4						
Subarea "A"	23.40	24	7	1	12	9.27
Subarea "B"	17.90	30	8	1	16	10.24
Subarea "C"	2.05	150	14	1	25	6.76
Subarea "D"	3.05	150	14	1	25	6.76
Subarea "E"-1	27.00	150	14	1	25	6.76
Subarea "E"-2	98.84	100	18	1	40	7.48
Area No. 5						
Native area	84.70	100	18	1	40	1.48

Angeles River watershed fell slightly above the damage curve developed in this report.

Erosion Potential for Storms for a Fifty Year Period

Erosion from the watershed was considered to be proportional to damage through the 7 to 50 year frequencies. From the data available, it is impossible to develop any well authenticated erosion analysis, so in any case, observation and judgment are the principal sources of information.

The upper part of the erosion potential curve is felt to be conservation. Below the 7 year frequency erosion potential is definitely above damage. Observation has shown that considerable erosion occurs in the average yearly rains; and the fact that often more than one yearly storm occurs necessitates that the curve for the 25 extra storms of this magnitude be made actually to include a greater number than 25. In addition, on agricultural land, especially storms up to a 7 year frequency, are capable of cutting through the loose top soil to the plough sole at which point much greater resistance to erosion is encountered. For this reason the "erosion potential" curve below the 7 year frequency has been drawn in as indicated by curve D in chart No. H-6.

Similar to the damage curve, the percent of erosion potential of all storms in terms of the 50 year storm is 891%. The ratio of total 50 years of potential erosion to the erosion magnitude of the 1938 storm (the erosion factors) for each of the sub-areas are given in col. 7 of Table No. H-4. Other values in table H-4 are the same as in table H-3.

Los Angeles River watershed fell slightly above the damage curve developed in this report.

Erosion Potential for Storms for a Fifty Year Period

Erosion from the watershed was considered to be proportional to damage through the 7 to 50 year frequencies. From the data available, it is impossible to develop any well authenticated erosion analysis, so in any case, observation and judgment are the principal sources of information. The upper part of the erosion potential curve is felt to be conservative. Below the 7 year frequency erosion potential is definitely above damage. Observation has shown that considerable erosion occurs in the average yearly rains; and the fact that often more than one yearly storm occurs necessitates that the curve for the 25 extra storms of this magnitude be made actually to include a greater number than 25. In addition, on agricultural land, especially storms up to a 7 year frequency, are capable of cutting through the loose top soil to the plough sole at which point much greater resistance to erosion is encountered. For this reason the "erosion potential" curve below the 7 year frequency has been drawn in as indicated by curve D in chart

No. H-6.

Similar to the damage curve, the percent of erosion potential of all storms in terms of the 50 year storm is 89%. The ratio of total 50 years of potential erosion to the erosion magnitude of the 1938 storm (the erosion factors) for each of the sub-zones are given in col. 7 of Table No. H-4. Other values in Table H-4 are the same as in Table H-3.

FLOOD PREVENTION OPERATIONS BVI
Los Angeles River Watershed
California

AUG. 1953

By the Los Angeles Flood Control District • San
Fernando Valley Soil Conservation District •
City of Los Angeles and Community Groups.

In cooperation with

U.S. DEPARTMENT OF AGRICULTURE, SOIL CONSERVATION SERVICE
PACIFIC REGION

Wm. M. M.

FLOOD CHANNELS - HEADWATERS LOS ANGELES RIVER

COOPERATIVE PROJECT

SAN FERNANDO VALLEY SOIL CONSERVATION DISTRICT

LOS ANGELES COUNTY FLOOD CONTROL DISTRICT

U.S. DEPARTMENT OF AGRICULTURE - SOIL CONSERVATION SERVICE



The Bell-Dayton and Calabasas Creek Flood Channels completed as cooperative projects during 1948 - 49, just ahead of a disastrous brush fire that denuded the entire Bell-Dayton Creek watershed. The system drains 24,000 acres to form the headwaters of the Los Angeles River.

LOS ANGELES RIVER WATERSHED FLOOD PREVENTION PROGRAM CALIFORNIA

Southern California presents a flood control problem as critical as any in the United States, owing to the proximity of highly developed agriculture and densely settled urban areas adjacent to rugged mountain ranges which periodically project violent flood flows upon the settled plains.

Los Angeles and nearby cities are located on an alluvial plain about thirty miles wide lying between the Pacific Ocean and the San Gabriel Mountain range. From the outwash fans at the northern edge of the alluvial plain to the tops of the higher peaks, there is a difference in elevation of as much as 4,500 feet. The mountains are formed largely of granitic rock, heavily faulted and deeply weathered, yielding large quantities of rock debris by normal erosional processes.

When the characteristic local storms of high intensity occur, the steep canyons of these mountains discharge torrential flows upon the agricultural, suburban, and urban areas lying along the mountain front at the edge of the valley floor. Storms of that type, and even storms of less intensity, cause considerable movement of silt, sand, and fine gravel from watershed lands into streets, roads, agricultural and urban land, and into the drainage systems. Damages resulting from these local torrential floods are out of all proportion to the size of the area from which the floods originate. They are greatest where communities or intensively cultivated agricultural lands lie on the alluvial fans below the canyon mouths, or where they extend into the canyons themselves.

The program recommended by the Soil Conservation Service for the improvement of the Los Angeles River watershed in aid of flood prevention represents a plan of attack on the flood problem by treating the mountain portions of the watersheds to prevent excessive debris movement, and by introducing land use measures in the valley areas to reduce damages occurring on agricultural lands.

The flood control prevention objectives are: (1) reduction in amounts of sedimentation and such retardation of water flow as practicable; (2) improvement of vegetative cover of the range areas and protection thereof from fire; (3) surface protection of cultivated lands during winter precipitation periods by cover crops and mulching; (4) surface retention of water by contour operations; (5) increase of rate of infiltration into the soil mantle by improved soil structure; and (6) interception and diversion of excess waters from cultivated fields and other runoff areas into stabilized outlet channels.

The accomplished work illustrated by words and photography following this page was carried out under authorization of Section 6 of the Flood Control Act approved June 22, 1936, in cooperation with the Los Angeles Flood Control District, the City of Los Angeles, the San Fernando Valley Soil Conservation District, local groups and private individuals.

All rights-of-way and 50 percent or more of construction and engineering costs have been provided by local cooperating agencies. Approximately 70 percent of total program installation costs have been borne by local agencies and individuals. All maintenance responsibilities and costs are the responsibility of the same local agencies and individuals.

LOS ANGELES RIVER WATERSHED
CALIFORNIA



LOS ANGELES RIVER WATERSHED

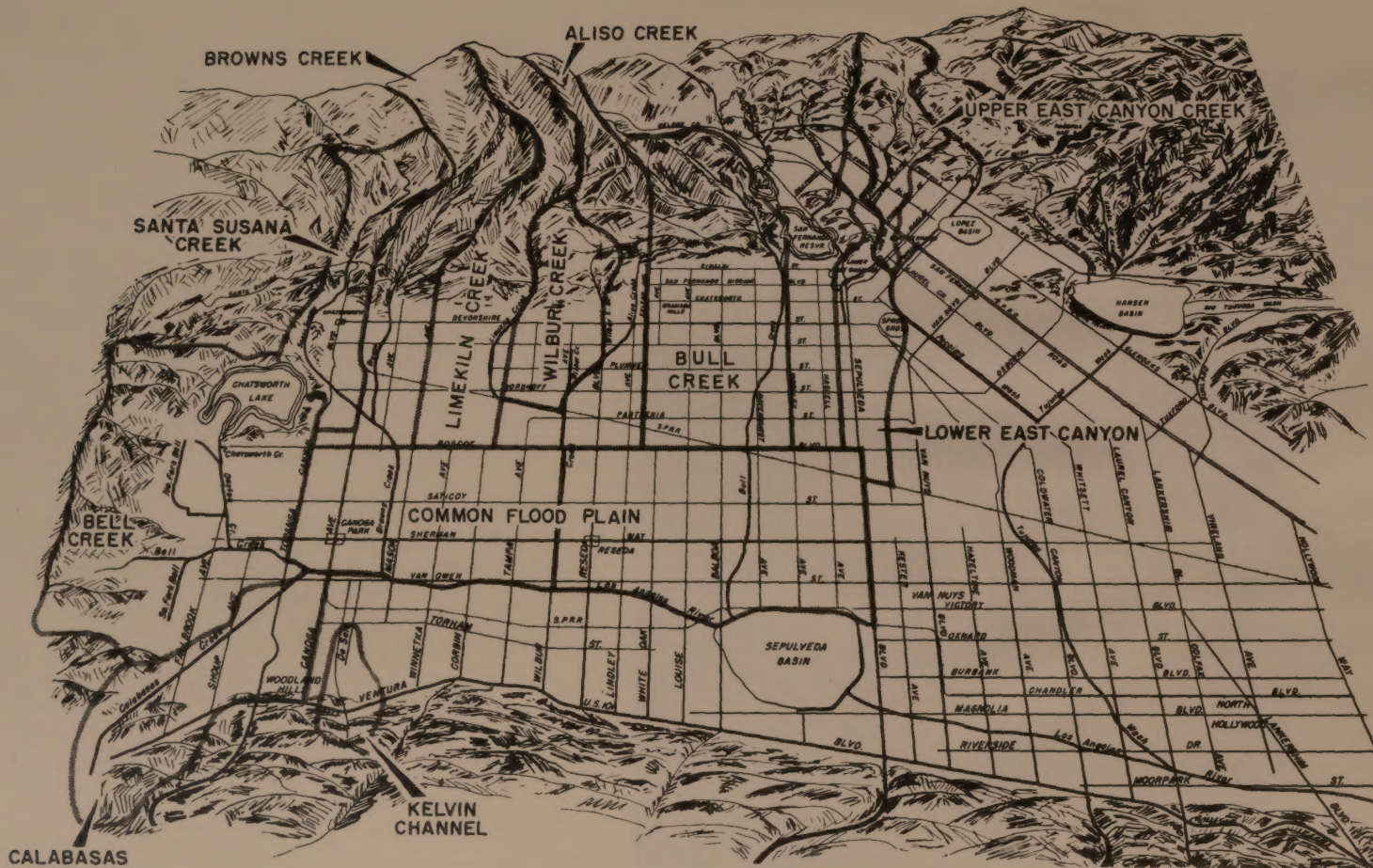
Drainage Area - 839 sq. mi.

Subwatersheds improved as of April, 1953.

1. Wilbur
2. Bell
3. Calabasas - Lower reach
4. Aliso - Middle reach
5. Lower East (Wilson-East)
6. Browns - Lower reach

Subwatersheds scheduled for improvement.

1. Upper East Canyon
2. Bull Creek
3. Browns Creek - Upper reach
4. Limekiln
5. San Fernando Reservoir (Grapevine-Stetson)
6. Santa Susana
7. Kelvin
8. Calabasas - Upper reach
9. Aliso Creek - Upper reach



GENERAL LOCATION - SUB WATERSHEDS
LOS ANGELES RIVER WATERSHED
CALIFORNIA

San Fernando Valley Flood Channels - 1953

7-L-14214

ALISO-WILBUR CREEK FLOOD CONTROL
COOPERATIVE PROJECT
SAN FERNANDO VALLEY SOIL CONSERVATION DISTRICT
LOS ANGELES COUNTY FLOOD CONTROL DISTRICT
U.S. DEPARTMENT OF AGRICULTURE — SOIL CONSERVATION SERVICE
1948



WILBUR CREEK SUB WATERSHED PROJECT

Wilbur Creek is a tributary of Aliso Creek, a subwatershed of the Los Angeles River. Wilbur Creek flows southward from the Santa Susana Mountains and joins the main Aliso Creek south of the junction of Devonshire Street and Reseda Boulevard, and is within the San Fernando Valley Soil Conservation District. It consists of 4.26 square miles, or approximately 2,722 acres. About 1,700 acres of this watershed are under cultivation, of which 1,100 acres are irrigated and 600 acres are dryland cultivated. The remaining area of 900 acres which excludes streams, roads, farmsteads, etc., is in grass and brush cover; the only agricultural use of which is for limited grazing. The upper portion of the watershed is precipitous and subject to geologic as well as man-induced erosion.

The improvement of Wilbur Creek was accomplished under two separate projects, the division point being at Devonshire Street. Both the lower and upper section was revetted with pipe and wire fencing and stabilized with railroad rail and wire mesh structures. Head control structures of reinforced concrete were installed. This type of channel protection was considered the most consistent with development trends and economy of the area.

Control of field drainage adjacent to the channel banks is provided by corrugated metal pipe overpour structures. Without effective use of this type of control, channel side slopes would be badly eroded and undercut.

Secondary channel improvement was accomplished through farmer-district agreements between the San Fernando Valley Soil Conservation District and individual farmers or local groups of property owners. These secondary channels are tributary to Wilbur Creek channel, and carry runoff waters, both flood and irrigation, from the adjacent agricultural lands, providing needed protection.

LOWER WILBUR CREEK FLOOD CONTROL PROJECT

Construction Period: 6/24/47 to 12/22/47

Length of Project: 1.9 miles

Description 1½:1 side slopes

Bottom width: 15 to 43 feet

Pipe and wire revetment.

Rail and wire stabilizers.

Corrugated metal pipe overpour
structures.

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Wilbur Avenue debris basin at lower end
of project.



Completed channel upstream from debris basin.



Completed improvement at junction of Aliso and
Wilbur Creeks.



Junction of Wilbur and Aliso Creeks during
flood runoff.



Upper end of project before channel improvement.



Upper end of project after channel improvement.

UPPER WILBUR CREEK FLOOD CONTROL PROJECT

Period: 10/17/47 to 4/14/48

Length of Project: 1.8 miles

Description: 1½:1 Side Slopes
7 to 15 ft. bottom width.
Pipe and wire revetment.
Rail and wire stabilizers.
Beginning of project at Corrugated metal pipe overpour
structures.



Beginning of project before channel improvement.



Beginning of project after channel improvement.



Before channel improvement.



After channel improvement.



Upper end of completed project showing small drop developed at stabilizer.



Head control structure at upper end of project.



A group enterprise channel used to collect runoff water from a young citrus orchard.



A group enterprise diversion channel which is tributary to Wilbur Creek.



Concrete block drop structure constructed in a secondary or group enterprise channel.



Vegetated group enterprise channel constructed through a permanent pasture.

ALISO CREEK FLOOD CONTROL
COOPERATIVE PROJECT
CITY OF LOS ANGELES
LOS ANGELES COUNTY FLOOD CONTROL DISTRICT
SAN FERNANDO VALLEY SOIL CONSERVATION DISTRICT
U.S. DEPARTMENT OF AGRICULTURE - SOIL CONSERVATION SERVICE



ALISO CREEK SUB WATERSHED PROJECT

The Aliso Creek subwatershed project extends southward from the Santa Susana Mountains, joins Wilbur Creek south of the junction of Reseda Boulevard and Devonshire Street and then flows through the communities of Northridge and Reseda, joining the Los Angeles River approximately three miles upstream from the Sepulveda Flood Control Basin, all within the San Fernando Valley Soil Conservation District. The subwatershed contains approximately 8,000 acres. The extreme upper watershed is leased by an oil company which has developed oil wells and storage tanks in the area.

Approximately 25 percent of this area is classified as residential, suburban, or miscellaneous land use with some of the acreage in small farm units of three acres or less. Five percent of the area is suitable for range use and sixteen percent is steep mountainous watershed. The remaining 54 percent is devoted to various agricultural land uses.

Oil field operations, roads, etc., in the upper watershed provide most of the debris from this area and are one of the more active sediment sources in the watershed. Debris originates in the raw road cuts and fills resulting from oil well and road development as well as excessive erosion along the canyon side slopes, caused by undercutting of the bases of these slopes as the mountain channel bottoms erode.

Aliso Creek channel has been improved from its junction with Wilbur Creek to Devonshire Street. The channel section was revetted with pipe and wire fencing and bottom stabilization secured with reinforced concrete structures.

A pilot program of road slope stabilization was initiated early in 1949 in upper Aliso watershed. Six slopes were stabilized by mulching and plantings.

ALISO CREEK FLOOD CONTROL CHANNEL

Contract Period: 4/3/50 to 12/22/50

Length of Project: 1.2 miles

Description: 1½:1 side slopes

21' bottom width

Reinforced concrete stabilizers

Pipe and wire revetment

Corrugated metal pipe overpour
structures.



Lower end of project before channel improvement.



Lower end of project after channel improvement.



Upper end of project before channel improvement.



Upper end of project after channel improvement.



Upper end of project during flood runoff.



Reinforced concrete stabilizer showing drop
developed after flood flow.

UPPER ALISO ROAD SLOPE STABILIZATION PROGRAM



Portion of Aliso Creek subwatershed showing
road and other developments in the area.



Comparison of treated and untreated
road slopes.



Typical road slope before treatment.



Typical slope after treatment.

BELL CREEK and ARROYO CALABASAS SUB WATERSHED PROJECTS

The Bell Creek and Arroyo Calabasas subwatersheds, with their tributaries of Dayton, South Fork Bell, North Branch Bell and Chatsworth Creeks, form the most westerly drainages in the San Fernando Valley. These project areas lie within the San Fernando Valley Soil Conservation District. The area of these subwatersheds is about 23,900 acres. General use by acreage is as follows:

Suburban	2,067 acres
Pasture and range	6,269 acres
Brushy watershed	8,844 acres
Truck and field crops	2,698 acres
Orchard	1,320 acres
Cereal grain or hay	2,707 acres

Because of types of soil, vegetative cover and terrain, silt contribution of Calabasas, Bell Creek and tributaries is quite low. Conversely, runoff contribution is moderately high, resulting in spread of flood water over a wide area, much of which is urban, with many streets.

The primary purpose of the program in the Arroyo Calabasas and Bell Creek subwatersheds was the channeling and removal of flood waters which collected during heavy rains. These watersheds formerly had no well defined channels in the valley floor reaches; flood waters spread out over agricultural and residential lands and flowed along roads until they reached the Los Angeles River, flooding the town of Canoga Park in the process. Since improvement of these channels, flood waters have been well contained and no inundation of agricultural lands, improvements and streets has occurred. Residents of the community of Canoga Park have voiced their appreciation for the control of flood waters and the subsequent protection of this area.

BELL CREEK SUB WATERSHED FLOOD CONTROL CHANNELS

Bell Creek Flood Control Channel

Contract Period: 7/1/48 to 11/8/48
 Length of Project: 2.3 miles
 Description: 1½:1 side slopes
 16 to 35 ft. bottom width
 Corrugated metal pipe overpour structures
 520 ft. rail and wire revetment and groins

South Fork Bell Creek, Dayton Creek and Chatsworth Creek Flood Control Channels

Contract Period: 4/13/49 to 7/7/49
 Length of Project: 2.5 miles
 Description: 1½:1 side slopes
 12 to 3
 12 to 21 ft. bottom width
 Corrugated metal pipe overpour structures

Calabasas Creek

Contract Period: 8/19/49 to 1/12/50
 Length of Project: 1.8 miles
 Description: 1½:1 side slopes
 16 ft. bottom width
 Asphaltic concrete overpour structures



Lower end of project at junction of Bell and Calabasas Creeks before channel improvement.



Junction of Bell and Calabasas Creeks after channel improvement.



Junction of Bell Creek and Dayton Creek.
Channel improvement completed.



Junction of Bell Creek and Dayton Creek
during flood runoff. Note high water
line on side slopes.



South Fork Bell Creek during flood runoff.
About 3 years after channel construction.



Dayton Creek during flood runoff. About three
years after channel construction.



Calabasas Creek before channel improvement.



Calabasas Creek after channel improvement.

WILSON-EAST FLOOD CHANNEL

COOPERATIVE PROJECT

SAN FERNANDO VALLEY SOIL CONSERVATION DISTRICT
LOS ANGELES CITY AND COUNTY FLOOD CONTROL DISTRICT
U.S. DEPARTMENT OF AGRICULTURE-SOIL CONSERVATION SERVICE



The Wilson-East flood channel consists of 1.4 miles of concrete lined ditch and culverts to carry flood waters, draining toward the critical valley floor area in the vicinity of Sepulveda Blvd., to the pervious gravels of the Pacoima Wash.



Beginning of project; looking upstream from
junction with Pacoima Wash



Completed project.



Before construction.



After construction.



Completed channel looking upstream toward box
culvert section.



Pouring concrete for invert of box culvert
section.



Placing pneumatically applied mortar on
sidewalls of transition section.



Placing concrete on channel side slopes of 1:1



Completed debris basin showing inlet structure
at upper end of project.

UPPER EAST CANYON SUB WATERSHED PROJECT

The Upper East Canyon subwatershed lies to the north and west of the City of San Fernando. The East Canyon channel flows southward from the San Gabriel Mountains to the Los Angeles River. All of this subwatershed is within the San Fernando Valley Soil Conservation District. Upper East Canyon channel is poorly defined and inadequate for even moderate flood flows. The flood waters overflow the channel banks, erode fields in the upper reaches, inundate agricultural lands, and deposit sediment in the lower reaches. The roads traversing this area are unimproved and serve as outlets for the farm drainage systems. The roads running north and south collect the water and carry it to East Canyon channel. These roads are eroding and are a source of sediment.

The paving of Bledsoe Street, which will be utilized as a flood channel, represents one of the initial steps in the overall work plan in this area, to be followed by the paving of Tyler Street, another tributary to Upper East channel.

BLEDSON STREET

Contract Period: 7/23/52 to 11/1/52
Length of Improvement: 0.9 miles
Description: Asphaltic concrete combined
roadway and flood channel
Constructed section, 34' wide.

The paving of Bledson Street, which will be utilized as a flood channel, represents one of the initial steps in the overall work plan in this area, to be followed by the paving of Tyler Street, another tributary to Upper East Channel.



Junction of East Canyon Channel and Bledsoe
Street before construction.



After construction.



Looking down Bledsoe Street before improvement.



Looking down Bledsoe Street after improvement.

BROWN'S CREEK FLOOD CHANNEL
COOPERATIVE PROJECT
SAN FERNANDO VALLEY SOIL CONSERVATION DISTRICT
LOS ANGELES CITY AND COUNTY FLOOD CONTROL DISTRICT
U.S. DEPARTMENT OF AGRICULTURE - SOIL CONSERVATION SERVICE



The lower reach of the Brown's Creek Flood Channel was completed as a cooperative project during 1952 and consists of 1.3 miles of open bottom channel with asphalt lined side slopes. Flood waters from this watershed which formerly inundated portions of the communities of Canoga Park and Reseda are now carried directly to the Los Angeles River

BROWNS CREEK SUB WATERSHED PROJECT

The Browns Creek subwatershed is located in the northwestern portion of the San Fernando Valley near the communities of Chatsworth and Canoga Park. This area covers 18.7 square miles, or 11,967 acres. The upper mountainous watershed is rolling to sharply broken land primarily used for grazing. The northeastern portion contains an oil field with considerable road development. The area on the gently sloping valley floor is devoted to various agricultural uses, and in localized areas to residential and suburban use.

The improved portion of Browns Creek extends from the Los Angeles River to a point 2,000 feet above Saticoy Street. Before improvement, this reach of channel was inadequate in size and flood waters emptied into Mason Street at its intersection with Saticoy Street, flowing down Mason Street to the Los Angeles River. Flood waters now can flow in a southerly direction directly to the Los Angeles River in a trapezoidal section controlled with asphalt lining side slopes of 1-3/4:1 and an earth bottom stabilized with reinforced concrete structures.

BROWNS CREEK FLOOD CONTROL CHANNEL

Contract Period: 6/2/52 to 2/17/53

Length of Improvement: 1.4 miles

Description: 1-3/4:1 asphaltic concrete
lined side slopes

Reinforced concrete stab-
ilizers

Asphaltic concrete overpour
structures.



Junction of Los Angeles River and Browns Creek
flood channel.



Placing asphaltic concrete on channel
side slopes.



Before channel construction.



Construction progress - showing excavation and asphalt lining below bottom grade.



Before channel construction.



After channel construction.

